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RLAY DESIGN AND REFLECTION CRACKING ANALYSIS FOR RIGID PAVEMENTS

Vol. 2 Design Procedures

August 1977
Final Report

DEPARTMENT OF
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Offices of Research & Development
Washington, D.C. 20590

FOREWORD

These reports present the results of research conducted by Austin Research Engineers, Inc. for the Federal Highway Administration (FHWA), Office of Research, under contract DOT-FH-11-8544, Phases II and III. This work was a part of FCP Project 5D, "Structural Rehabilitation of Pavement Systems." There are two volumes: Volume I discusses the development of the rigid overlay design procedure and Volume 2 is a user's manual. Phase I of this contract consisted of the development of an overlay design procedure for flexible pavements.

The rigid overlay design procedure uses linear elastic layered theory as the basic model to compute stresses and strains in the pavement system, which are used as inputs to the fatigue and reflection cracking models. The fatigue criteria developed is based on the performance of rigid pavements at the AASHO Road Test. The reflection cracking criteria developed resulted from a study of the mechanics of reflection cracking and literature reviews.

Copies of these reports are being distributed by memorandum to individual researchers. Additional copies may be obtained from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

Charles F. Scheffey
Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

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TE
662
.A3
no.
FHWA-
RD-
77-67

Technical Report Documentation Page

1. Report No.
FHWA-RD-77-67

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Overlay Design and Reflection Cracking Analysis for Rigid Pavements
Vol. 2. Design Procedures

5. Report Date
August 1977

6. Performing Organization Code

7. Author(s)
Harvey J. Treybig, B. Frank McCullough, Phil Smith and Harold Von Quintus

8. Performing Organization Report No.

9. Performing Organization Name and Address
Austin Research Engineers Inc
2600 Dellana Lane
Austin, Texas 78746

10. Work Unit No. (TRAIS)
FCP 35D2-202

11. Contract or Grant No.
DOT-FH-11-8544

12. Sponsoring Agency Name and Address
Offices of Research and Development
Federal Highway Administration
U. S. Department of Transportation
Washington, D.C. 20590

13. Type of Report and Period Covered
Phases II and III
Final Report

14. Sponsoring Agency Code

15. Supplementary Notes
FHWA Contract Manager: R. A. McComb (HRS-14)

16. Abstract
This manual presents design procedures for flexible and rigid overlays of rigid pavements as well as a reflection cracking analysis procedure for flexible overlays. The design procedure includes an evaluation of the existing pavement based on nondestructive deflection testing, condition surveys, and materials sampling and testing. Based on this information the pavement is divided into separate design sections and each section is classified according to its condition of cracking into one of the three categories: (1) pavement with no cracking or Class 1 and 2 cracking, (2) pavement with Class 3 or 4 cracking, or (3) pavement that will be mechanically broken up.

An analysis to determine the required overlay thickness is then made based on the category to which the existing pavement is assigned. The overlay analysis makes extensive use of elastic layered theory and selects the overlay thickness based on the concept of failure by fatigue cracking. For flexible overlays an analysis can be performed to determine if reflection cracking should be expected to occur.

The design procedure uses four computer programs for the pavement evaluation, overlay thickness design, and reflection cracking analysis. Input guides and illustrative problems for the use of these programs are presented in this report.

This volume is the second in a series. The other is: Overlay Design and Reflection Cracking Analysis for Rigid Pavements - Vol. 1. Development of New Design Criteria, FHWA Report No. FHWA-RD-77-66. The first volume presents the development of the design procedure given in this report.

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TRANSPORTATION
APR 2 1979
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17. Key Words
Overlay design, pavement design, overlays, rigid overlays, reflection cracking, fatigue cracking, flexible overlays, deflection analysis, pavement evaluation

18. Distribution Statement
No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
166

22. Price

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

PREFACE

This is the second of a two-volume series concerning the design of flexible and rigid overlays for rigid pavement and analyses of flexible overlays for reflection cracking. Volume 1 which has been published separately, presents the development of the overlay design procedures given in this manual.

The work presented in these two reports was accomplished by a team including Harvey J. Treybig, B. F. McCullough, Phil Smith, Harold Von Quintus, Frank Carmichael, Peter Jordahl, Stephen Seeds, and Jack O'Quin. W. R. Hudson also provided technical assistance in certain phases of the project.

Support for the project was provided by the Federal Highway Administration, Office of Research and Development, under Contract No. DOT-FH-11-8544. We are grateful for the technical coordination provided by Mr. Richard McComb, Contract Manager during this phase of the contract.

Austin Research Engineers Inc

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SECTION 1

INTRODUCTION

This design manual describes the use of the pavement overlay design procedure developed for the Federal Highway Administration's FCP Project 5D, Structural Rehabilitation of Pavement Systems. The development of the procedure is discussed in an accompanying Volume I report (Ref. 1)[1].

1.1 Objective

This manual outlines a procedure for the thickness design of both flexible and rigid overlays of rigid pavements. Previous reports written on this project present a procedure for flexible overlays of flexible pavements (Ref. 2[2], 3[3]) that is based on some of the same design concepts as presented here. This manual contains all elements necessary for the user to prepare thickness designs for overlays of rigid pavements.

1.2 Scope of Procedure

The procedure covers both jointed and continuous rigid pavements and bonded and unbonded overlays. It covers existing pavements that have remaining life, those that are substantially cracked, and those that are in such deteriorated condition that they will be mechanically broken up into small pieces. The procedure infers that overlay materials and construction specifications will not differ from those now in use in highway design and construction. However, it does include some non-conventional materials testing methods.

1.3 Design Concepts

The procedure is based primarily on design criteria to prevent fatigue cracking, but also includes a design check to minimize reflection cracking.

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[1] Austin Research Engineers Inc, "Overlay Design and Reflection Cracking Analysis for Rigid Pavements, Volume I - Development of New Design Criteria", FHWA Report No. FHWA-RD-77-66, August 1977.

[2] Austin Research Engineers Inc, "Asphalt Concrete Overlays of Flexible Pavements, Volume 1 - Development of New Design Criteria", FHWA Report No. FHWA-RD-75-75, August 1975.

[3] Austin Research Engineers Inc, "Asphalt Concrete Overlays of Flexible Pavements, Volume 2--Design Procedures" Report FHWA-RD-75-76, August 1975.

It consists of collection of data from the field, laboratory testing, traffic computations, and use of computer programs to determine overlay thicknesses. Figure 1.1 is a flow chart of the basic steps.

The design procedure, by including a nondestructive evaluation of the existing pavement, permits the designer to vary overlay thickness along the highway as required by field conditions and also to select a reliability level for design. With modern construction methods, variations in overlay thickness can be readily built as long as adequate transition length between thickness changes is maintained for riding quality. Thus, through the use of this procedure, a more economical total cost may result than with most traditional approaches to overlay design.

Linear elastic layered theory is used as an analytical model to make design computations. This theory is the backbone of the main fatigue analysis computer program, RPOD1 (Ref. 1). A flow diagram showing the various types and conditions of existing pavements and types of overlays that are handled in the computer program is shown in Figure 1.2.

The design procddure is automated in the form of four separate computer programs which are as follows:

1. PLOT2 for plotting deflection profiles (Ref. 3)
2. TVAL2 for determining design sections (Ref. 3)
3. RPOD1 for determining overlay thickness to prevent fatigue cracking (Ref. 1)
4. RFLCR1 for determining overlay thickness to minimize reflection cracking (Ref. 1)

Thus, the designer is required to make only minor hand computations, these being aids in determining computer program input data. However, if the user desires, he can make hand plots in lieu of using the program PLOT2 and hand statistical computations in lieu of using the program TVAL2.

1.4 Equipment Requirements

The hardware requirements for using this procedure include deflection testing equipment such as Dynaflect, Road Rater, Benkleman Beam or deflectograph, and laboratory testing equipment for resilient modulus of soils and other unbound base or subbase materials. Test equipment to measure the dynamic modulus of elasticity for asphalt concrete and portland cement concrete is also desirable.

The computer software which is part of the procedure is a series of programs which require a computer system such as the CDC 6600, IBM S/360, or the Univac 1108.

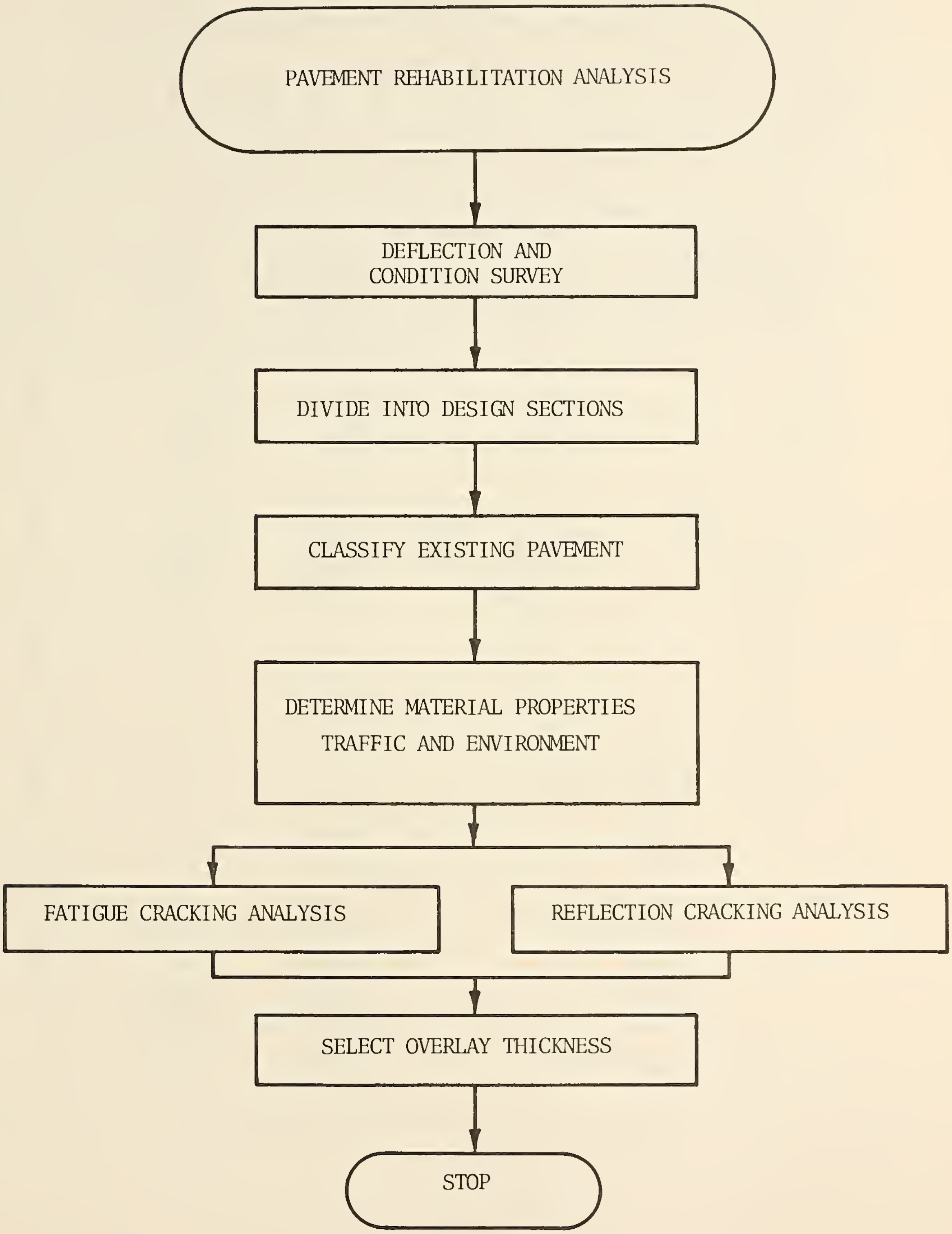
PAVEMENT REHABILITATION ANALYSIS
DEFLECTION AND CONDITION SURVEY
DIVIDE INTO DESIGN SECTIONS
CLASSIFY EXISTING PAVEMENT
DETERMINE MATERIAL PROPERTIES TRAFFIC AND ENVIRONMENT
FATIGUE CRACKING ANALYSIS
REFLECTION CRACKING ANALYSIS
SELECT OVERLAY THICKNESS
STOP

Figure 1.1. Flow chart of rigid pavement overlay design procedure.

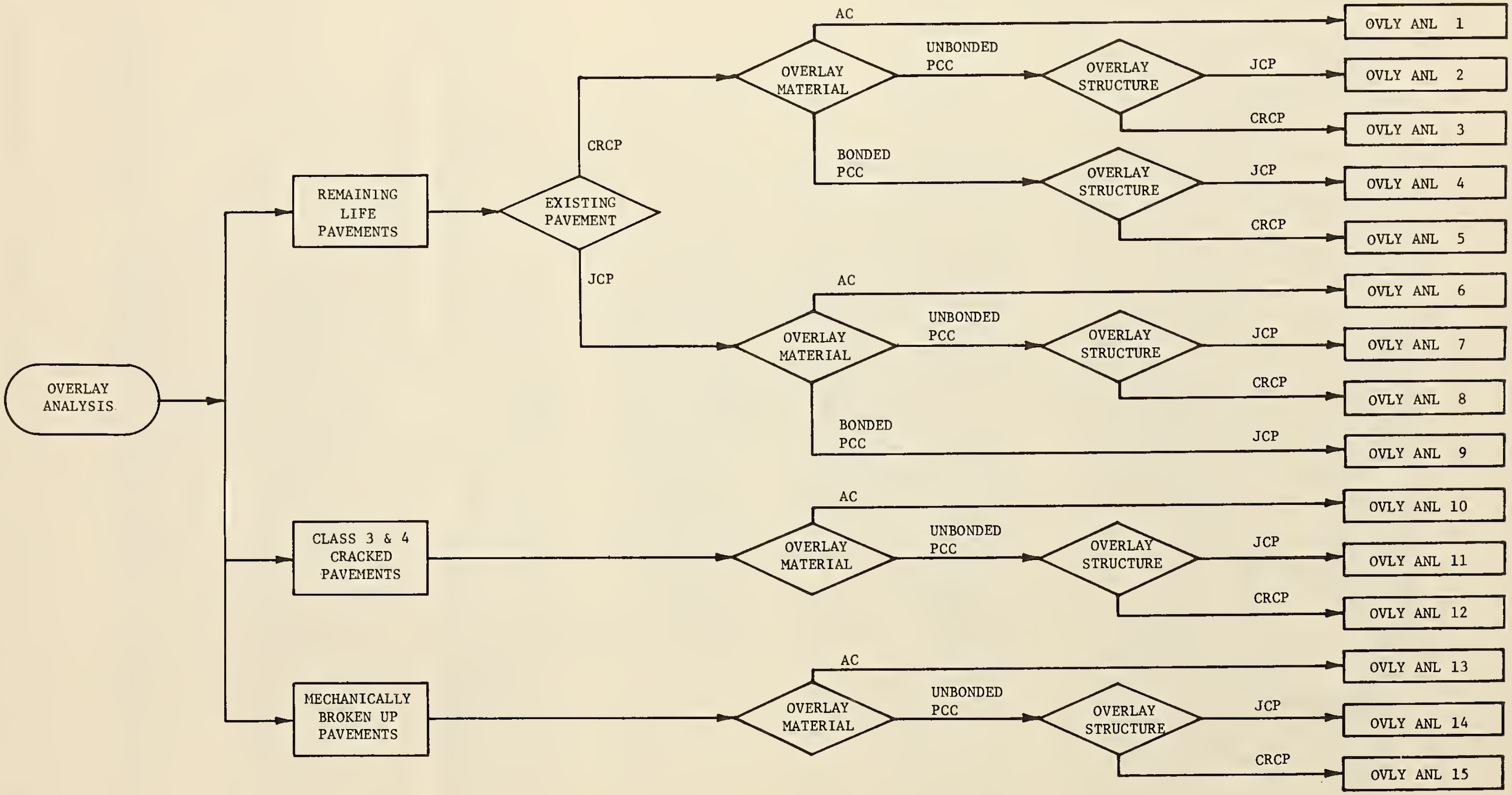

Figure 1.2. Analysis system for overlay of rigid pavements.

1.5 Contents of Design Manual

Section 2 of this manual discusses the requirements for deflection testing, condition surveys, and traffic computations. Section 3 discusses the selection of design sections based on the deflection and condition survey data which includes use of the computer programs PLOT2 and TVAL2. A hand method for statistical analysis is given which can be used in lieu of TVAL2. Section 4 describes the necessary materials sampling and testing. Section 5 discusses the designation of the proper overlay design analysis to be used. Section 6 describes the use of the fatigue analysis program RPOD1. Section 7 describes the use of the reflection cracking program RFLCR1. Section 8 presents an overlay design example problem. The appendices include a condition survey procedure, computer program input guides, and materials testing procedures.

SECTION 2

GENERATION OF DESIGN PROCEDURE INPUTS

The design procedure requires input from the following areas:

1. Deflection testing
2. Condition surveys
3. Traffic data

2.1 Deflection Testing

Deflection testing is used to measure the response of the in-service pavement to loads. From this behavior pattern, areas of equal performance and material properties can be derived.

2.1.1 Equipment Type - Deflection measuring equipment such as the Dynaflect (Ref. 4)[1], the Road Rater (Ref. 5)[2] or any other equipment which will give satisfactory deflection results may be used. Both Dynaflect and Road Rater are available on a rental basis or for purchase. The equipment lends itself to rapid testing, thus making it possible to thoroughly investigate a pavement economically and rapidly. Deflections measured with a Benkleman Beam and an 18,000 pound (8172kg) single axle load may also be used.

2.1.2 Recommended Testing Conditions - The design procedure is based on measurements that were made during the season of the year yielding the maximum deflection. It is recommended that the user also measure deflections at the time of year yielding the maximum values. For other seasons, the user should develop corrections to relate the measurements to the worst or maximum condition. This manual offers no seasonal adjustment factors for translating deflection measurements made in any season other than the maximum period.

---

[1] Swift, Gilbert, "Dynaflect - A New Highway Deflection Measuring Instrument", Proceedings, 48th Annual Tennessee Highway Conference, University of Tennessee, 1966.

[2] Scrivner, F. H. and W. M. Moore, "An Electro-Mechanical System for Measuring the Dynamic Deflection of a Road Surface Caused by an Oscillating Load", Research Report 32-4, Texas Highway Department, Texas Transportation Institute, 1964.

2.1.3 Sampling Frequency and Procedure - The testing recommended includes at least one deflection profile along the outer wheelpath of the existing roadway. The spacing between the measurements should be a minimum of 100 feet (30.5m). For two directional roadways, it is desirable to obtain two lines of deflection profiles, one on either side of the center line in the outside wheel path. Each line should have the measurements spaced 100 feet (30.5m) apart, but staggered 50 feet (15.25m) between the lines, thus providing profile data with 50-foot (15.25m) spacing between measurements. For divided highways, deflection profiles are required in outside lanes of both roadways on a staggered basis.

For undivided highways the two deflection profiles should be combined into one that represents the entire width of roadway. However, for divided highways, the pavements on either side of the median should be considered to have separate deflection profiles. Two profiles will give adequate coverage of most highways. These measurements, however, need to be located between cracks in a good interior portion of the slab, spaced at regular intervals and so documented. The following is a suggested guideline of spacings for deflection tests for various conditions.

TABLE 2.1 GUIDELINE FOR DEFLECTION MEASUREMENTS

Condition of Location	Spacing of Measurements
Rolling terrain	100 feet (30.5m)
Numerous cut to fill transitions	100 feet (30.5m)
Level with uniform soil	250 feet (76.25m)

In addition to slab interior deflection measurements for the determination of a deflection profile, it is necessary to make measurements of deflection at the slab corners if the existing pavement is a jointed concrete pavement. This data will be needed later in determining the degree of load transfer. These measurements should be kept separate and not included in the deflection profile, but should be made at the same time as the interior measurements, to conserve time and money.

2.2 Condition Surveys

As part of the site investigation, the condition of the existing pavement should be carefully documented. Condition survey information should be obtained which includes such items as an accurate inventory of the different types and amount of cracking, spalling, joint condition, faulting, pumping, blowups, and some inventory of roughness. It is suggested that the condition surveys be done at the same time as the deflection testing. This enables the technicians to note and document locations of cracking, repairs, etc., relating to the location of deflection measurements. Appendix A includes some condition survey techniques that may be used.

2.2.1 Cracking - Cracking shall be defined and recorded according to the AASHO definitions, i.e., Class 1, Class 2, Class 3, and Class 4 (Ref. 6)[1].

Class 1 includes fine cracks not visible under dry surface conditions to a man with good vision standing at a distance of 15 feet (4.58cm). Class 2 cracks are those that can be seen at a distance of 15'(4.58cm), but which exhibit only minor spalling such that the opening at the surface is less than 1/4 inch (.64cm). A Class 3 crack is defined as a crack opened or spalled at the surface to a width of 1/4 inch (.64cm) or more over a distance equal to at least one-half the crack length, except that any portion of the crack opened less than 1/4 inch (.64cm) at the surface for a distance of 3 feet (.92cm) or more is classified separately. A Class 4 crack is defined as any crack which has been sealed.

Condition surveys of the existing pavement can be conveniently made on reasonably large-scaled maps, thus making it possible to record the distressed areas directly. The condition surveys provide important data for explaining variations observed in the deflection profiles and also differences in materials properties determined from laboratory investigations. A comparison of the deflection profile and the observed distress should be considered in formulating the materials sampling plan, Section 4.1. Furthermore, the observed cracking type present on the existing surface becomes a decision criterion relative to the method of characterization of the existing pavement and the kind of analysis performed.

2.2.2 General Observations - The condition survey shall include some recording of other general information relevant to the pavement such as drainage areas, soil changes, and cut/fill transition areas. Construction plans for the existing roadway, if available, offer information relative to changes in cross section which will be unknown until any borings are made. Some measurement of profile or roughness is desirable in a condition survey. In this design procedure the roughness profile is only considered in a qualitative way in the selection of design sections.

2.3 Traffic Information

Traffic information is required for the design procedure in terms of 18 kip (8172kg) equivalent single axle load applications determined in accordance with AASHO Interim Guide for the Design of Pavement Structures-1972 (Ref. 7)[2]. The total number of load applications experienced on the existing surface shall be estimated. The number of load applications shall also be projected for the anticipated life of the overlay.

---

[1] "The AASHO Road Test, Report 5, Pavement Research", Special Report 61E, Highway Research Board, 1962.

[2] "AASHO Interim Guide for Design of Pavement Structures", American Association of State Highway and Transportation Officials, 1972.

2.3.1 Design Lane Traffic - If the traffic projection represents the total of all lanes for both directions of travel, the traffic must be distributed by direction and lanes for design purposes as follows:

$$18KSAD = (18KSA) \cdot DDF \cdot LDF \quad (2.1)$$

where

18KSA = Total 18 kip (8172kg) single axle loads expected in both directions,

DDF = Directional distribution factor, the ratio of traffic in a given direction to the total traffic,

LDF = Lane distribution factor, the ratio between the traffic in the lane of interest and the one-directional traffic, and

18KSAD = The 18 kip(8172kg) single axle loads experienced or expected in the design lane.

Directional distribution is normally made by assigning 50 percent to each direction unless special conditions warrant some other distribution. In regard to lane distribution, the controlling lane is generally the outside lane. If an agency has developed lane distribution factors for facilities with two or more lanes in each direction these should be used. Table 2.2 may be used as a guideline for selecting the lane distribution factor. If there is doubt as to which factor to apply, it is suggested that the most conservative range be used. The equation must be solved for both conditions of traffic described in paragraph 2.3.

TABLE 2.2 LANE DISTRIBUTION FACTORS FOR MULTILANE ROADWAYS (After Ref. 7)

Total Number of Lanes, One Direction	Lane Distribution Factor
2	1.0
3	0.8-1.0
3+	0.4-0.6

SECTION 3

SELECTION OF DESIGN SECTIONS

Using the nondestructive deflection test data, a highway can be divided into various design sections, which are areas where the pavement responds or deflects differently under the load.

3.1 Deflection Profiles

The deflection data obtained in the site investigations, excluding joint deflections, are plotted in the form of profiles throughout the length of the roadway as shown in Figure 3.1. Profiles from separate lanes shall be combined according to location or station number. These plots may be made manually or by using the computer program PLOT2. Instructions for using PLOT2 are in Appendix B.

3.2 Preliminary Design Sections

The deflection profiles from Section 3.1 shall be divided into areas of similar deflection. The limits of each design section should be recorded in terms of station number or mile points. A pavement may exhibit as few as one or two different levels of deflection, but variations may be so great in the subgrade support or surface condition that there may be as many as 7-10 different areas on a two mile (3.22km) length of roadway. Information from the condition survey (Section 2.2) shall be used as additional guidelines for dividing the profiles into sections. The deflection profile sections should also be compared with the cracking surveys to show any differences in the deflection and the performance of the pavement. Areas of different cross sections should be assigned different sections of deflection profile. Normally, this will be obvious in the deflection measurements. The reason for this is related to the structural analysis of the existing pavement.

3.3 Statistical Hypothesis Testing

Adjacent design sections of the same cross section should be checked to see if they are significantly different or whether they are from the same population of data. Standard statistical methods for testing of significance of the difference between two samples such as the hypothesis tests for equal means should be used for making this check (Ref. 8)[1]. The following steps and formulas are used to make this test:

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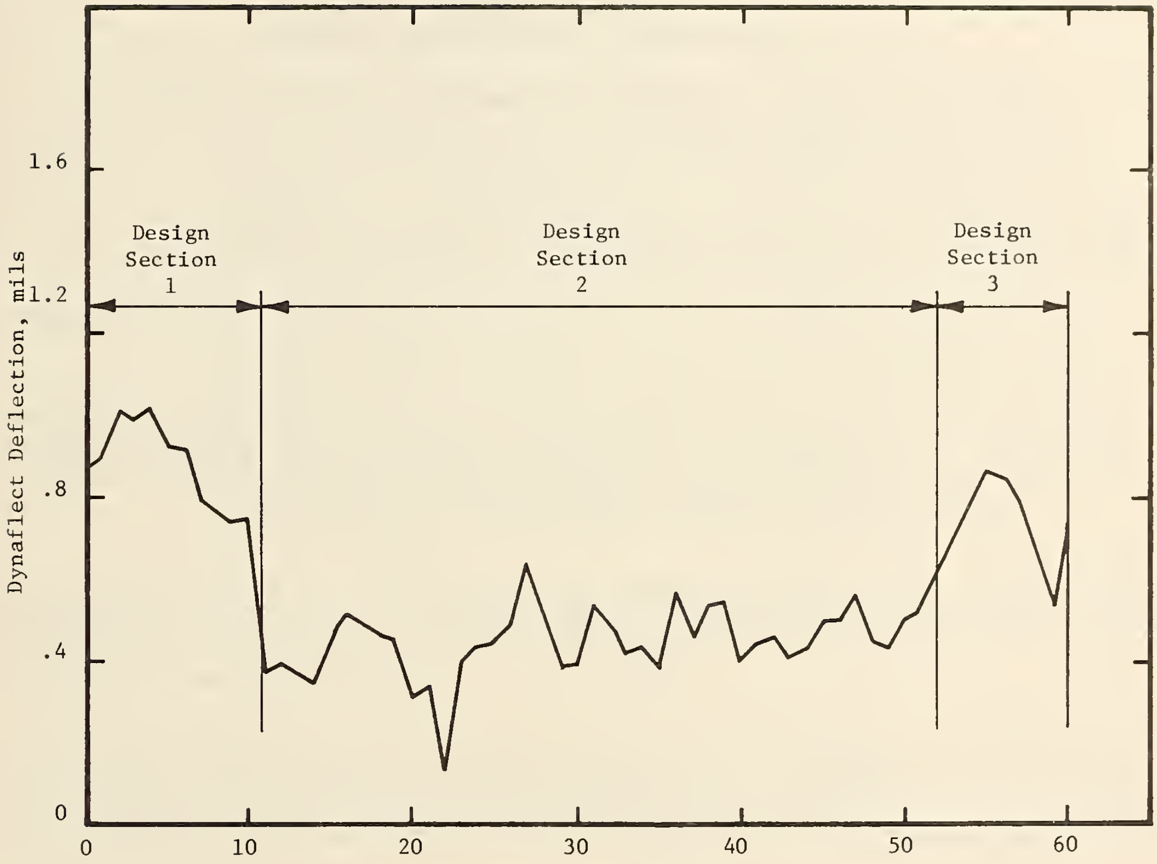
[1] Alder, Henry L. and Edward B. Roessler, Introduction to Probability and Statistics, Third Edition, W. H. Freeman and Company, San Francisco, California, 1964.



Distance Along Roadway, Stations

1 mil=.0025cm
1 station=30.5m

Figure 3.1. Sample deflection profile.

a_i, b_i = individual measurements or variates in sections designated 1 or 2 respectively

$\bar{a}$, $\bar{b}$ = mean value of measurements of variates in Sections 1, 2

n_a, n_b = number of variates in Sections 1, 2

d_f = the number of degrees of freedom

Step 1 - Calculate the mean ($\bar{a}$) from the section 1 data:

$$\bar{a} = \frac{\Sigma a_i}{n_a} \quad \ldots\ldots\ldots\ldots \quad (3.1)$$

Step 2 - Calculate the mean ($\bar{b}$) from the section 2 data:

$$\bar{b} = \frac{\Sigma b_i}{n_b} \quad \ldots\ldots\ldots\ldots \quad (3.2)$$

Step 3 - Calculate the "pooled estimate of the standard deviation" (S) from the two sections. This way the standard deviation determined is not affected by any difference which may exist between the means of each section.

$$S = \left[\frac{\sum_{i=1}^{n_a} (a_i - \bar{a})^2 + \sum_{i=1}^{n_b} (b_i - \bar{b})^2}{n_a + n_b - 2} \right]^{1/2} \quad \ldots\ldots \quad (3.3)$$

Step 4 - Determine the best estimate of the standard deviation of the mean of n_a sample variates for section 1, $S_{\bar{a}}$

$$S_{\bar{a}} = \frac{S}{(n_a - 1)^{1/2}} \quad \ldots\ldots\ldots\ldots \quad (3.4)$$

Step 5 - Do Step 4 for Section 2,

$$S_{\bar{a}} = \frac{S}{(n_b - 1)^{1/2}} \quad \ldots\ldots\ldots\ldots \quad (3.5)$$

Step 6 - Calculation from Step 4 and Step 5.

$$S_{(\bar{a} - \bar{b})} = (S_{\bar{a}}^2 + S_{\bar{b}}^2)^{1/2} \quad \ldots\ldots\ldots\ldots \quad (3.6)$$

Step 7 - The hypothesis to be tested is that the difference in mean values of the two parent populations from which the a_i and b_i were sampled differ by a value $^M(\bar{a}-\bar{b})$, here = 0. This hypothesis implies that if a very large number of samples were taken for a_i and b_i, their means would differ by $^M(\bar{a}-\bar{b})$. Calculate Student's t.

$$t = \frac{(\bar{a}-\bar{b}) - {}^M(\bar{a}-\bar{b})}{S\ (\bar{a}-\bar{b})} \qquad (3.7)$$

Step 8 - Assume an appropriate significance level for the test. This is the probability that the hypothesis (equal means) will be rejected even though true. Obtain from a table* of the Student's t distribution the t value corresponding to the number of degrees of freedom (n_a+n_b-2) and the chosen significance level (usually designated by γ and α, respectively).

Step 9 - Compare the two values of t. If the computed t is larger than the tabular value, the hypothesis is false at the assumed level of significance, and the two sets of deflections come from parent populations with different means; stated another way, the two sets of deflections come from sections which have significantly different mean deflections, and which therefore should be analyzed separately.

If two adjacent sections are not significantly different, they should be combined into one and that one checked against the next section. This procedure will establish the design sections, each of which then becomes a separate design problem.

The designer selects the significance level at which the deflection differences are tested; a level of 5 percent is recommended for general use. The statistical check may be made either by hand or by use of computer program TVAL2. A description of the program and its input guide are presented in Appendix C.

3.4 Determination of Design Deflection

The deflection data for each design section has previously been analyzed to obtain its mean value and standard deviation. The standard deviations give an indication of the variations which exist within the design sections. The design deflection for any given design section is a function of the mean deflection, the variation, and the realiability level selected for design. The reliability level, R for design is the percentage of deflections that would exceed the chosen design deflection on the assumption of a normal distribution for the deflections. Similarly the confidence level, C, is the percentage of deflections that would fall below the selected design deflection value on the same assumption. Hence confidence level C = 1-R. The design deflection shall be computed using the following relation:

---

* t-value table not reproduced here because of copyright laws.

$$W_d = \bar{w} + z\,S_{dw} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3.8)$$

where:

w_α = design deflection based on Dynaflect measurements on Benkleman beam with 18-kip (8172kg) load, in. (1 in=2.54cm)

$\bar{w}$ = mean deflection, in. (1 in=2.54cm)

S_{dw} = standard deviation of mean deflection, in. (1 in=2.54cm)

z = distance from mean to selected significance level on a normal distribution curve. The selected significance level is equal to R/2.

Table 3.1 is a list of z values corresponding to various design confidence or reliability levels.

TABLE 3.1 Z VALUES FOR VARIOUS CONFIDENCE LEVELS

Design Confidence Level	Reliability (R)	z Value
50	50	0
75	25	0.674
90	10	1.282
95	5	1.645
97.5	2.5	1.960
99	1	2.330

The design deflections calculated for a specific design confidence level, 95% for example, means that on the assumption of a normal distribution for the deflections, 95% of the deflections measured fall below the design deflection.

The computer program TVAL2 computes the design deflection for each design section also. Thus, Equation 3.8 and Table 3.1 do not have to be utilized if TVAL2 is run.

SECTION 4

MATERIALS SAMPLING AND TESTING

This section describes the materials sampling and testing requirements of the procedure. The testing methods noted are for determining the quasi-elastic properties for use in the design procedure.

4.1 Sampling Plan

At this point, the design sections are all established and the plan for materials sampling must be formulated. It is recommended that at least one boring be made in each design section, and for extremely long sections more than one boring may be desirable. If it is impossible to obtain this many borings, the absolute minimum sampling should be for the extreme conditions, i.e., materials sampling should include core borings at selected locations throughout the length of the pavement being investigated.

4.1.1 Type of Sampling - These borings should include as a minimum, cores of any paving layers which are intact, such as (1) existing concrete, (2) cement stabilized, (3) asphalt stabilized, or (4) other chemically treated materials. Any granular or gravel layers which are encountered should be sampled by collection of augered materials from the drill hole. Unbound materials should be sampled in sufficient quantity for remolding of specimens. For this remolding, the inplace moisture and density are required and are easily obtainable if nuclear equipment is available. In materials where it is possible to push such samples, Shelby tubes should be used to obtain undisturbed samples. The drill hole should be very carefully logged so as to accurately document the layer thicknesses in the existing pavement structure. Normally a total depth of 10 feet (3.05m) is sufficient for pavement borings.

4.2 Asphalt Concrete and Portland Cement Concrete Testing

Materials properties required for asphalt concrete and portland cement concrete are Poisson's ratio, modulus of elasticity, and flexural strength (PCC only). Other properties pertinent to mix design and construction will be necessary, but for thickness design purposes only these three properties are required.

4.2.1 Modulus of Elasticity - The asphalt concrete overlay material shall be tested for its dynamic modulus of elasticity. At this time there is no ASTM standard for this test, but there are established procedures. The designer should determine the modulus over a range of temperatures and then select the modulus based on his selected temperature(s). A temperature of 70°F (21.1°C) is suggested for design. In the absence of an ASTM standard for the test procedure, recommended procedures are furnished in Appendix D. The modulus of elasticity for portland cement concrete may be determined according to ASTM C469. The flexural strength may be determined according to ASTM C78.

4.2.2 Poisson's Ratio - Normally tests will not be performed for Poisson's ratio, as it does not vary significantly. It is recommended that a value of 0.3 be used for asphalt and .15 for concrete in the design analyses. The overlay design computer program has default values of 0.3 and .15 built in for Poisson's ratio of asphalt and concrete, respectively.

4.3 Base Materials Testing

All base and subbase materials must be tested for their modulus of elasticity. Poisson's ratio tests are not necessary. Default values in the computer program are 0.20 for stabilized bases and .40 for granular bases.

4.3.1 Bound Materials - Bound base or subbase materials will in most cases be either asphalt or cement treated materials. When cement treated base layers are present in existing flexible pavements these layers must be characterized for a modulus of elasticity. Undisturbed samples should be tested in compression to determine the modulus of elasticity using ASTM C469 or its equivalent. The value selected for design analyses should be the mean value of the tests conducted.

Asphalt treated base or subbase materials should be tested by the dynamic modulus test as described for asphalt concrete in Appendix D.

4.3.2 Unbound Materials - Usually the base and subbase materials will be disturbed samples thus requiring recompaction. The inplace density and moisture content should be determined if possible and the materials remolded at these values. Otherwise samples should be recompacted at optimum moisture content with not less than 95% of the density corresponding to that moisture content used for construction control. Base and subbase materials should be tested with confining pressures equal to the overburden pressure and if that is less than one psi (6.9kN/m^2), the tests should be unconfined. The tests should be performed with a deviator stress of 20 psi (138kN/m^2) if the total concrete thickness is six inches (15.24cm) or less and 10 psi (69kN/m^2) if it is greater than six inches (15.24cm). Recommended test procedures are included in Appendix E.

4.4 Subgrade Materials Testing

Usually subgrade samples will be undisturbed samples, and if that is not the case they should be treated similar to the base materials. Undisturbed subgrade samples should be tested with confining pressures equal to the overburden and over a range of repeated deviator stresses such as 2 to 12 psi (13.8 to 82.8kN/m^2). The laboratory tests should be performed with a minimum of four levels of deviator stress; 2, 5, 8 and 12 psi (13.8, 34.5, 55.2, and 82.8kN/m^2) are offered as recommended levels. The modulus values and corresponding deviator stresses serve as inputs to the computer program. Recommended test procedures are included in Appendix E. Characteristically, clay type soils will show a decrease in resilient modulus with increased applied stress while granular materials will be the opposite. A default value of 0.45 is used for Poisson's ratio of the subgrade.

4.5 Summary of Materials Properties

The properties that are needed in the analysis of the existing pavement and overlay design are summarized as follows:

Portland Cement Concrete - modulus of elasticity and Poisson's ratio
Asphalt Concrete - dynamic modulus of elasticity and Poisson's ratio
Base and Subbase - resilient modulus of elasticity and Poisson's ratio
Subgrade - resilient modulus of elasticity and the corresponding deviator stresses; Poisson's ratio

In lieu of testing to determine Poisson's ratio for the materials the following values are recommended and also fixed as default values should no values be input to the computer program:

Portland cement concrete	0.15
Asphaltic concrete	0.30
Stabilized bases	0.20
Granular bases	0.40
Subgrade	0.45

SECTION 5

DESIGNATION OF OVERLAY DESIGN CATEGORY

5.1 Existing Pavement Classification

Use of the design procedure requires that each design section be classified according to one of the following three categories:

1. Pavement with remaining life - A pavement falls in this category if it is uncracked or has class 1 or 2 cracking as determined according to Section 2.2.1.
2. Pavement with class 3 or 4 cracking - A pavement falls in this category if the condition survey indicates class 3 and 4 cracking as determined according to Section 2.2.1 or if the overlay design program RPOD1 computes the remaining life to be less than the established minimum of 12 percent (in this case, the program automatically changes the pavement from category 1 to category 2).
3. Pavement that will be mechanically broken up - A pavement falls in this category if it is in such poor condition that the designer feels it should be broken up to serve as a base material.

In some cases, severe cracking, faulting, pumping, and scaling can be locally repaired, thus upgrading the pavement condition from category 3 to category 2.

5.2 Types of Overlay Analyses

The category assigned to the pavement becomes an input to the computer program RPOD1 which then determines internally the proper overlay design analysis to use. The type of existing pavement and overlay must also be specified. The fifteen different analyses were previously shown in Figure 1.2. Nine of the analyses are for pavements with remaining life, three are for pavements with class 3 and 4 cracking, and three are for those that will be mechanically broken up.

When the existing pavement is a CRCP with remaining life, asphaltic concrete, bonded and unbonded JCP, and bonded and unbonded CRCP are acceptable overlays. When the existing pavement is a JCP with remaining life, asphaltic concrete, bonded and unbonded JCP, and unbonded CRCP are acceptable overlays. Bonded CRCP is not allowed for this case. When the existing pavement has class 3 or 4 cracking or will be mechanically broken up, asphaltic concrete, unbonded JCP, and unbonded CRCP are acceptable overlays. Bonded JCP and CRCP are not allowed for this case.

SECTION 6

USE OF OVERLAY DESIGN COMPUTER PROGRAM RPOD1

The computer program RPOD1 must be used to determine the overlay thickness needed to satisfy the fatigue cracking criterion. The information necessary to develop inputs for the program has been previously discussed in the first five sections. They are summarized in this section and then discussed in more detail as to their actual input format.

6.1 Outline of Program Operation

Basically, RPOD1 performs the following operations:

1. Determines the subgrade modulus based on measured deflections and laboratory tests on the subgrade material.
2. Computes the fraction of remaining life in the existing pavement from stresses in the pavement before overlay, when appropriate.
3. Computes the stress in the pavement surface for an 18-kip (8172kg) single axle wheel load for a range of overlay thicknesses varying between 3 and 12 inches (7.62 and 30.48cm).
4. Calculates the fatigue life of the pavement system for each overlay thickness based on the stresses computed.
5. Plots overlay thickness versus fatigue life and determines the overlay thickness necessary for specific lifetimes input by the designer.

6.2 Summary of Input Information

The information needed to determine the specific inputs for RPOD1 is summarized below, but not necessarily in the order that they are input.

1. Design deflection as determined using PLOT2, TVAL2, and the design deflection equation presented in Section 3 (Equation 3.8).
2. Load magnitude, tire pressure, and wheel configuration of the deflection measuring device.
3. Condition of the existing pavement surface, i.e., whether it is uncracked, has class 1 and 2 cracking, class 3 and 4 cracking, or will be mechanically broken up.
4. Ratio of corner to interior deflection if the existing pavement is jointed.
5. Presence or absence of voids beneath the existing pavement.
6. Number of equivalent 18-kip (8172kg) single axle loads the pavement has experienced to date and will experience during its lifetime - as determined in Section 2.3.
7. The material type, thickness, Poisson's ratio, and modulus for each layer in the existing pavement system.
8. Range of deviator stresses and corresponding modulus values determined in the laboratory tests of subgrade material.

9. Flexural strength of concrete.
10. Type of overlay and its modulus and Poisson's ratio.
11. Type of bond breaker, if any, and its thickness, modulus, and Poisson's ratio.

The program contains default values for the Poisson's ratio values based on material types; default values are also provided for bond breaker thickness and modulus. If the condition survey has shown the existing pavement to be a class 3 or 4 cracked PCC or one that will be mechanically broken up, the modulus value that is input for the surface layer will be automatically defaulted to predetermined values.

6.2 Input Guides

Program RPOD1 was written so that the required data could be input in a simple yet logical manner; problems dealing with nearly similar situations can be stacked by inputting for each problem after the first only the directives (data input cards) containing the item which is changed. For any one problem the directives can appear in any order, except that a PROBLEM directive must begin the data for each problem, and an END directive must follow the data for the last problem.

An input guide describing and making full use of this flexibility appears in Appendix F. For the new user, or one who is more familiar with an input guide rigidly prescribing card order and content, the guide in Appendix G is presented. It is highly recommended that a prospective user read both input guides, beginning with Appendix F, before preparing data; Appendix F has more general information about the structure of the data input, while Appendix G has more specifics as to the source of the required data. Either will serve after some familiarity is gained with the program.

6.3 Program Execution Information

RPOD1 requires approximately 50,000 octal (about 21,000 decimal) words of memory on a CDC CYBER 74 or a CDC 6600 computer, and requires approximately 8 to 10 seconds of CPU time for a complete problem. If the subgrade modulus for the first problem of several stacked together is applicable for the remaining problems, those remaining will execute in approximately 4 seconds each.

No peripheral equipment is required except a card reader and a line printer. If the program is on a permanent file, it can be executed from a remote teletype; the output is relatively compact and can be printed easily except for the printer plot of lifetime vs. thicknesses. If use of these plots is anticipated beyond a "quick glance", it is recommended that a copy of the output be obtained on a line printer.

SECTION 7

USE OF OVERLAY DESIGN COMPUTER PROGRAM RFLCR1

The computer program RFLCR1 is used to determine if the distress mechanism of reflection cracking will occur in a specified overlay design. The program is intended for asphaltic concrete overlays, although other materials can be analyzed by reviewing the procedure (Ref. 1) and recognizing the assumptions involved in its development. The model is applicable for existing concrete pavements classified as category 1 or 2 but not applicable to those in category 3, mechanically broken-up pavements. The program performs two functions: (1) it characterizes the existing concrete pavement through in-field measurements and (2) it calculates critical strains in the overlay for a specific design condition. The designer compares these tensile and shear strains to the strain at which cracking will occur to determine if reflection cracks will develop.

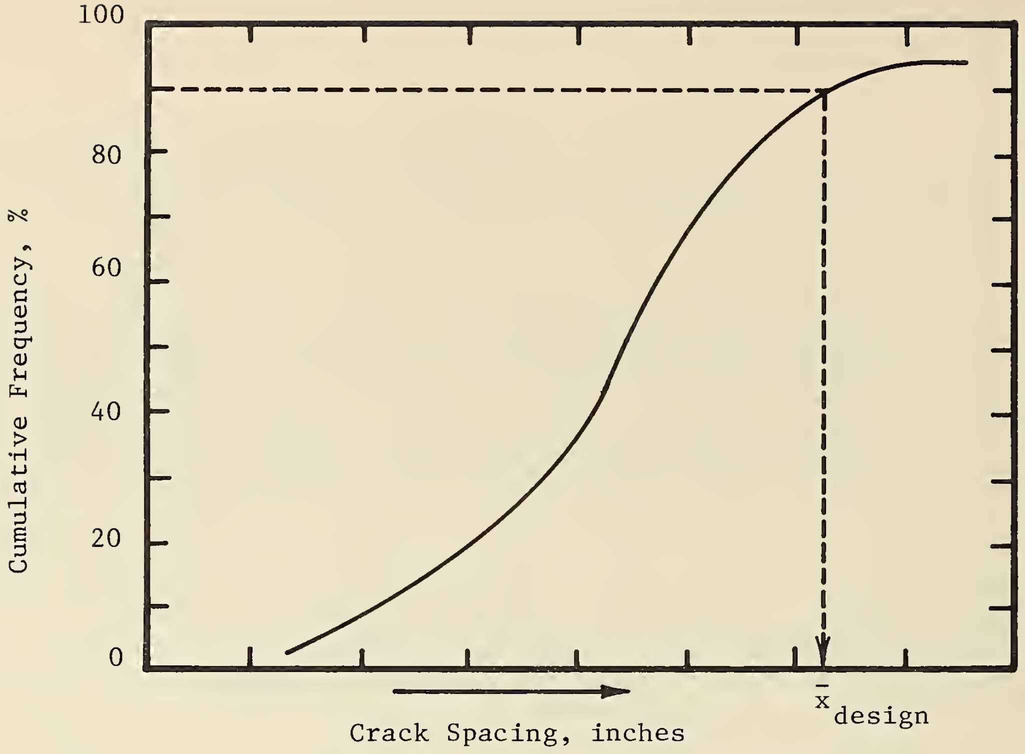
7.1 Input Information

To make these calculations, the program RFLCR1 requires certain variables and information which are listed and described below.

7.1.1 Joint or Crack Spacing - This value is determined from the condition survey and is dependent on the type of existing concrete pavement. For CRC pavements, crack spacing is always input into the program. Crack spacing is determined by an accurate inventory of the amount of cracking present. This is accomplished by measuring the distance of the transverse cracks in the pavement from a known reference point, with the use of a rolatape or measuring wheel and recorder. This will permit development of a cumulative frequency diagram as shown in Figure 7.1. Therefore, for different design levels an appropriate design crack spacing can be determined. It is recommended that a 90% design level be chosen for CRC pavements.

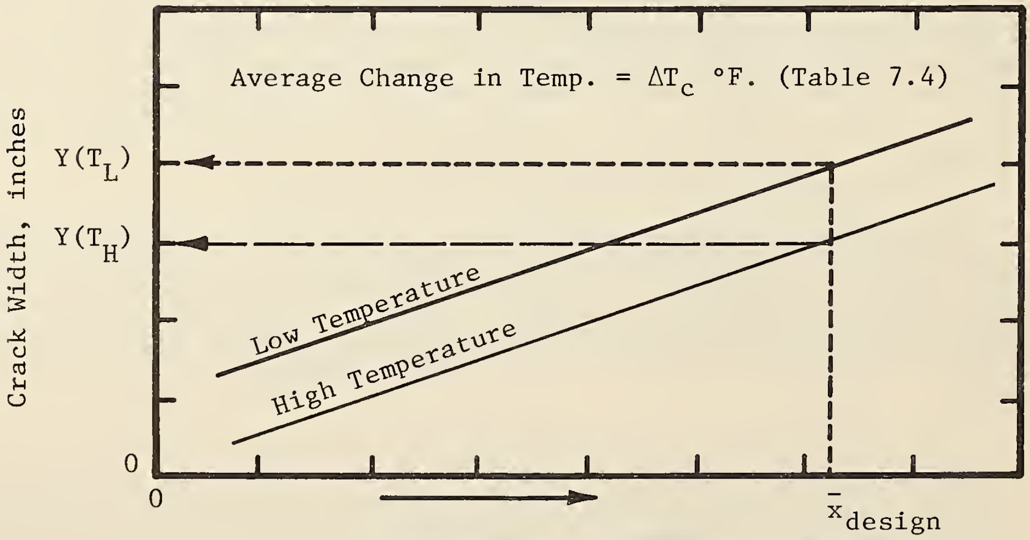
For jointed reinforced concrete (JRC) pavements it is recommended that joint spacing be used because this represents the most critical condition. In cases where the JRC pavement is cracked, the program can be used to evaluate crack measurements by developing Figure 7.1 as for CRC pavements. For this case joints should not be included as cracks.

For plain joint concrete (PJC) pavements, joint spacings should be used, unless the pavement contains thermal cracks which extend through the total thickness of the slab. In this case a cumulative frequency diagram as shown in Figure 7.1 should be developed; a 90% design level is recommended. For the case when slabs are not cracked or the cracks do not extend completely through the slab, joint spacing should be used.



1 in=2.54cm

Figure 7.1. Cumulative frequency diagram of crack spacing for a concrete pavement.



°C=.5554(°F-32)
1 in=2.54cm

Figure 7.2. Relationship between crack spacing and concrete movement at a crack for a temperature change and specific location or pavement.

7.1.2 Existing Concrete Properties - The modulus of elasticity of concrete is determined as for program RPOD1. Thickness and density can be determined from cores taken during materials sampling. In most cases the thermal coefficient of the existing concrete pavement will not be tested for, therefore Table 7.1 (Ref. 9)[1] is recommended as a source for an estimate based on the type of aggregate.

TABLE 7.1 THERMAL COEFFICIENT OF THE EXISTING CONCRETE PAVEMENT (Ref. 9)

Coarse Aggregate Type	Thermal Coefficient ($x10^{-6}$ in/in/°F)
Quartz	6.6
Sandstone	6.5
Gravel	6.0
Granite	5.3
Basalt	4.8
Limestone	3.8

1 in=2.54cm
^{o}C=.5554(^{o}F-32)

7.1.3 Friction Curve - The friction curve between the concrete and subbase is calculated by the program in order to characterize the existing pavement. In order to complete this calculation the movement of the slab at which sliding occurs must be input. Since very little data on friction curves exist, this value will probably not be known. Therefore, it is recommended that the values in Table 7.2 be used as a guide until more information can be compiled.

TABLE 7.2 MOVEMENT BETWEEN THE CONCRETE SLAB AND UNDERLYING LAYER AT WHICH SLIDING OR A CONSTANT FRICTION FORCE OCCURS

	Material	Movement at Sliding, inches
1)	Polyethylene Sheeting	0.02
2)	Granular Subbase	0.25
3)	Sand	0.05
4)	Sand Asphalt	0.02
5)	Plastic Soil	0.05

1 in=2.54cm

Table 7.2 was developed by reviewing as much data on friction curves as possible. From this review, it was determined that for some materials an increase in the overburden pressure will increase the friction curve.

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[1] "Mass Concrete for Dams and Other Massive Structures," Journal of the American Concrete Institutes, Proceedings, Volume 67, April, 1970.

Hence, the program has the capability to modify the friction curve for this effect if desired. It is recommended that for slabs which rest on plastic soils the increase in the friction curve not be used, but for granular type subbases the increase may be applied.

7.1.4 Existing Reinforcement Properties - When joint spacings are used in the program, reinforcement properties should not be input. Reinforcement properties are used only with crack spacings. A value of 29,000,000 psi ($2.001 \times 10^8 kN/m^2$) is recommended for the modulus of elasticity of the steel. The area and perimeter of steel per foot (1 ft=3.05m) width of pavement must be determined from information on past designs. When information on the existing pavement design is not available, cores should be taken to include the reinforcement to determine size and spacing of the bars.

It is recommended that Table 7.3 be used to determine the thermal coefficient for various type steels.

TABLE 7.3 THERMAL COEFFICIENTS FOR DIFFERENT TYPES OF STEEL

Type	Thermal Coefficient ($\times 10^{-6}$ in/in/°F)	
Steel (1020)	6.5	
Steel (1040)	6.3	
Steel (1080)	6.0	°C=.5554(°F-32)
Steel (18Cr-8Ni stainless)	5.0	1 in=2.54cm

If no fatigue cracking exists in the concrete pavement, the bonding stress between the concrete and steel can be computed using Equation 7.1 (Ref. 10)[1]. This assumes that all cracking has been thermally induced.

$$\mu = \frac{f_t A_c}{\ell \, \Sigma} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (7.1)$$

where:

μ = bonding stress, psi

f_t = concrete tensile strength as determined in accordance with ASTM C-496-71, psi

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[1] Bresler, Boris, Reinforced Concrete Engineering, John Wiley and Sons, 1973.

A_c = cross-sectional area per foot width of pavement, in^2/ft width

ℓ = one-half of the crack spacing, inches

Σ = perimeter of the steel per foot width of pavement, in/ft width

1 in=2.54cm
1 ft=.305m
1 psi=6.9kN/m^2

If fatigue cracking is present, the bonding stress can be theoretically determined using the following equation (Ref. 11)[1].

$$\mu = \frac{9.5\ (f_c)^{1/2}}{d} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (7.2)$$

where:

f_c = compressive strength of concrete determined in accordance with ASTM C 116-60T, psi

d = diameter of a reinforcing bar, inches

1 psi=6.9kN/m^2
1 in=2.54cm

It is recommended that Equation 7.1 be used when possible, and Equation 7.2 be used only when fatigue cracking is prevalent.

7.1.5 Characterization Measurement - Characterization measurements should be taken during the condition survey. Examples of the forms which can be used to determine the horizontal and vertical movements are given in Table 7.4 and 7.5, respectively.

Horizontal movement of the slab is determined by measuring crack or joint widths for different air temperatures. Since slab movement is dependent on temperature change, it is recommended to obtain these widths over the same temperature differential as closely as possible. This will enable the user to complete the data analysis for one temperature change, and reduce the error associated with different temperature differentials. Measurement of these widths can be achieved using a microscope with a graduated eyepiece capable of measuring to 0.001inch(.00254cm). In an attempt to reduce the error in reading, the microscope should be focused some distance below the concrete surface. Joints and cracks to be measured should be marked so the measurement can be taken at the same location for other temperatures. At least three readings should be taken at each location for a specific temperature and the average value recorded.

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[1] Ferguson, Phil M., Reinforced Concrete Fundamentals, 3rd Edition, John Wiley & Sons, 1973.

Table 7.4. Example of the form to be used in recording the necessary input data for the characterization of the existing concrete pavement.

HORIZONTAL MOVEMENTS

Job: ________________________________ Date: ____________

Description: ________________________ Sheet ______ of ______

Measurement Device: ____________________________________

Measurement Number or Location	Joint or Avg. Crack Spacing, ft. L	Air Temperature °F. T_L	Joint or Crack Width, in. $Y(T_L)$	Air Temperature, °F T_H	Joint or Crack Width, in. $Y(T_H)$	Temperature Change °F. ΔT_c	Joint or Crack Movement, in. $Y(T_L) - Y(T_H)$

°C=.5554(°F-32)
1 in=2.54cm
1 ft=.305m

Table 7.5. Example of the form to be used in collecting data for determining the design load transfer at discontinuities in the existing concrete pavement.

DIFFERENTIAL VERTICAL DEFLECTIONS

Job: ______________________________ Date: ______________

Description ______________________________ Sheet ______ of ______

Measurement Device ______________________________

Measurement Number or Location	Joint Width, in.	Temperature, °F	Deflection, in.		Differential Deflection, in. W_d	Percent Load Transfer, % L_T
			Loaded Joint W_L	Unloaded Joint W_U		

1 in=2.54cm
$^{\circ}C=.5554(^{\circ}F-32)$

For pavements with variable crack spacing, Figure 7.2, which relates average crack spacing to crack width, must be developed, using the data listed in Table 7.4, to determine the crack widths to be used with a specific crack spacing. When joint spacings are used,a cumulative frequency diagram as shown in Figure 7.3 must be developed, using the data listed in Table 7.4, to determine a joint movement to be used by the program. A value corresponding to a 90% design level is recommended.

Vertical movement of the slab can be obtained using a Benkleman Beam, a Dynaflect, or a differential deflection device that uses a dial gauge to measure relative movements between two adjacent slabs.

When using the Benkleman Beam as the measuring device, the load is placed on one side of the joint and the deflection recorded. The load is then moved across the joint and the rebound or differential deflection recorded. Measurements should be taken at the edge or corner of the pavement so the measuring device will not be in the deflection basin.

Dynaflect measurements should be taken in the wheel path. Two sensors are to be placed as closely together as possible and spaced equally distant from the pavement joint. This is done to minimize deflection differences due to the effects of the deflection basin. In this manner deflection on the loaded and unloaded slab can be obtained and the difference represents the differential deflection.

The differential deflection device measures directly the relative deflection between two adjacent slabs. Therefore, it cannot be used alone in defining load transfer. It can be used with other deflection measuring devices to obtain the information necessary for the required inputs.

A cumulative frequency diagram as shown in Figure 7.4 must be developed, using the data listed in Table 7.5, to determine the design load transfers. A 90% design level is recommended. The differential deflection is calculated by the following equation:

$$W_d = W_L - W_u \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (7.3)$$

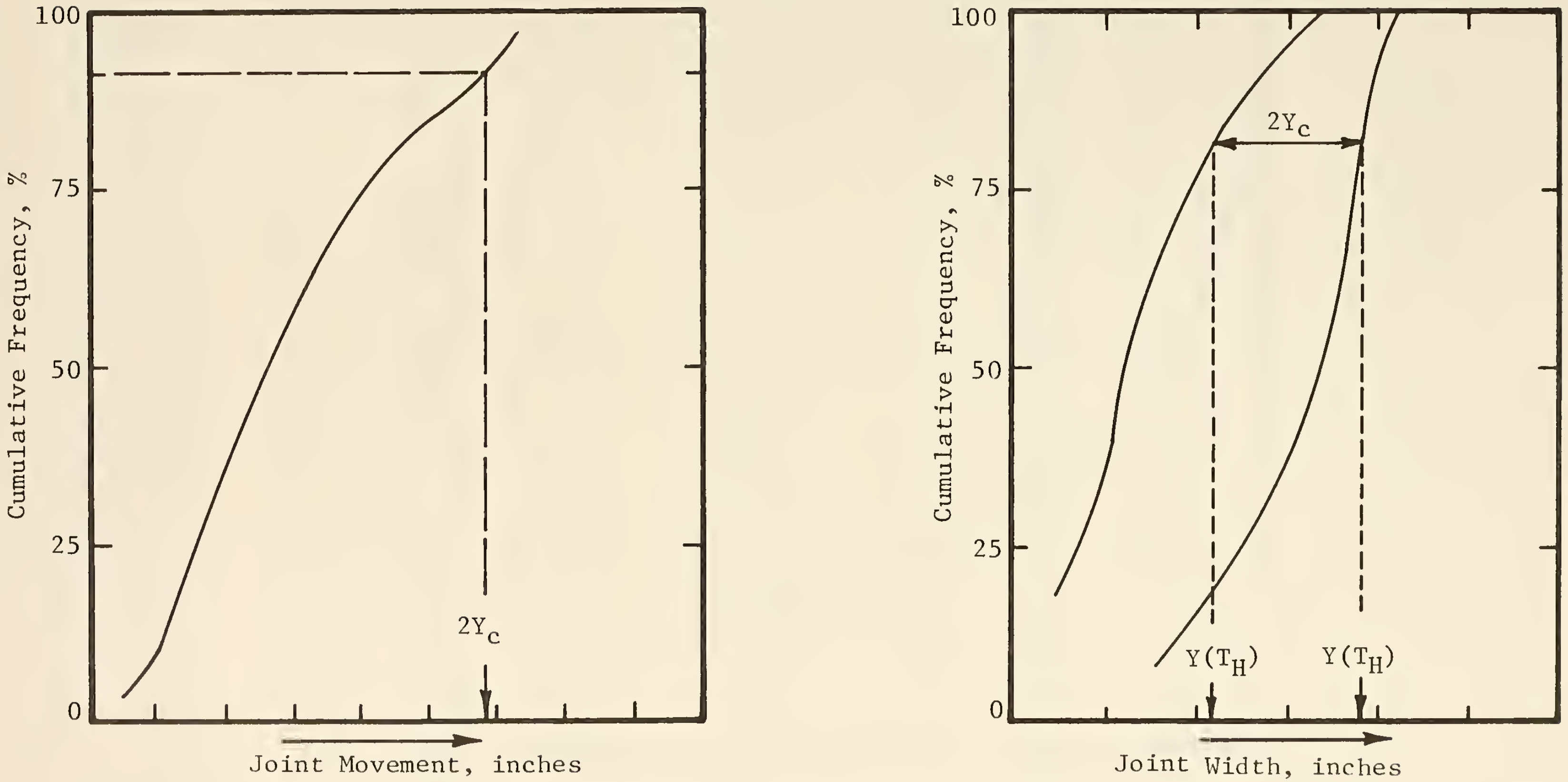
where:

W_d = differential deflection, inches (1 in=2.54cm)

W_L = deflection of the loaded joint, inches (1 in=2.54cm)

W_u = deflection of the unloaded joint, inches (1 in=2.54cm)

The percent load transfer can then be determined using equation 7.4.



(a) Determination of the design joint movement.

(b) Estimating maximum joint widths to be input into the program RFLCR1.

Figure 7.3. Illustration showing how the design joint movement, based on the characterization temperature change, can be obtained for an uncracked pavement.

1 in=2.54cm

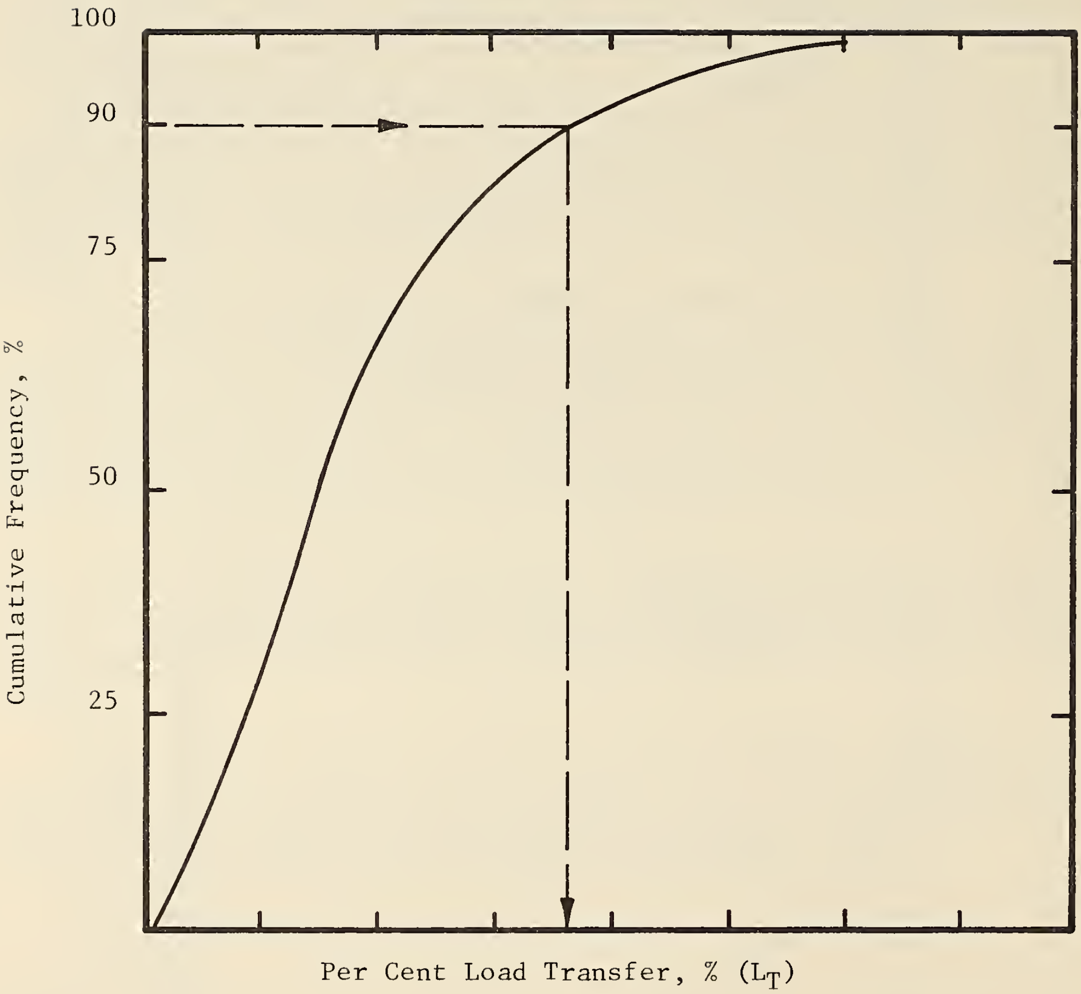


Figure 7.4. Illustration showing how the design differential deflection or load transfer can be obtained for some design level for an existing concrete pavement.

$$L_t = \left[1 - \frac{W_d}{W_L}\right] \times 100 \quad \text{(7.4)}$$

where:

L_t = percent load transfer

W_d = differential deflection, inches (1 in=2.54cm)

W_L = deflection of the loaded joint, inches (1 in=2.54cm)

The columns for joint width and temperature in Table 7.5 are for physical information. They are only used when it is anticipated that load transfer will be distinctly dependent on joint width.

Another value which needs to be input is the minimum temperature experienced by the pavement. This can be determined from past temperature records for the area in which the pavement is located.

7.1.6 Overlay Properties - The overlay properties are determined by the user for each specific design. The dynamic modulus of the overlay material can be determined in the same manner as for RPOD1. No test standard exists for determining the asphaltic concrete creep modulus. Therefore, Figures 7.5 - 7.7 (Ref. 12[1], 13[2]) can be used to estimate this value.

The penetration index of the bitumen can be estimated using Figure 7.5, knowing the ring and ball temperature and the penetration. The ring and ball temperature (T_o') can be determined in accordance with ASTM D36, and the penetration can be found using ASTM D5.

The stiffness modulus of the bitumen can be estimated using Figure 7.6, for the long term loading condition. A loading time of 20,000

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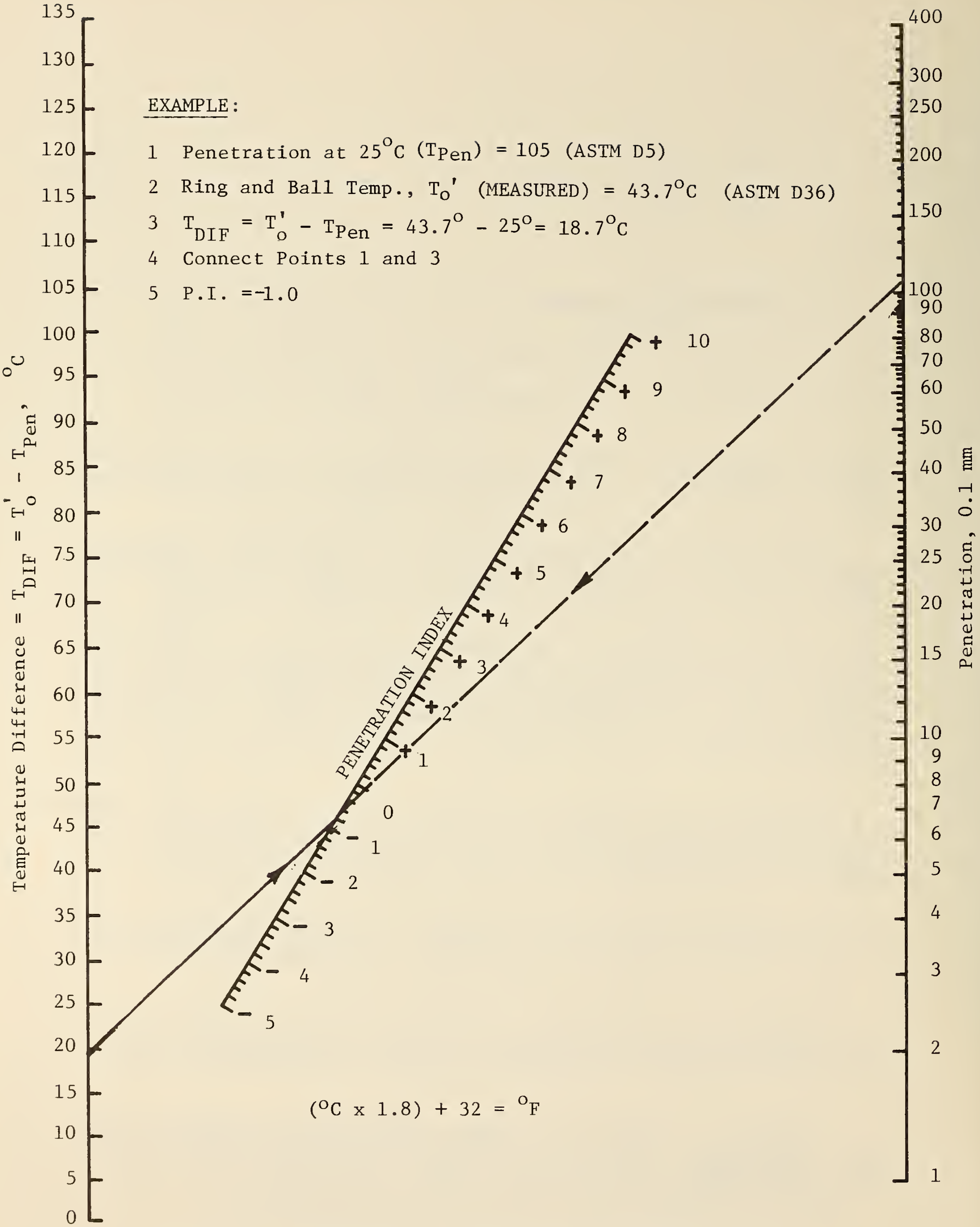
[1] McLeod, N. W., "Influence of Hardness of Asphalt Cement on Low-Temperature Transverse Pavement Cracking," Proceedings, Canadian Good Roads Association, 1970.

[2] Heukelom, W. and A. J. G. Klomp, "Road Design and Dynamic Loading," Proceedings, Association of Asphalt Paving Technologist, Volume 33, 1964.

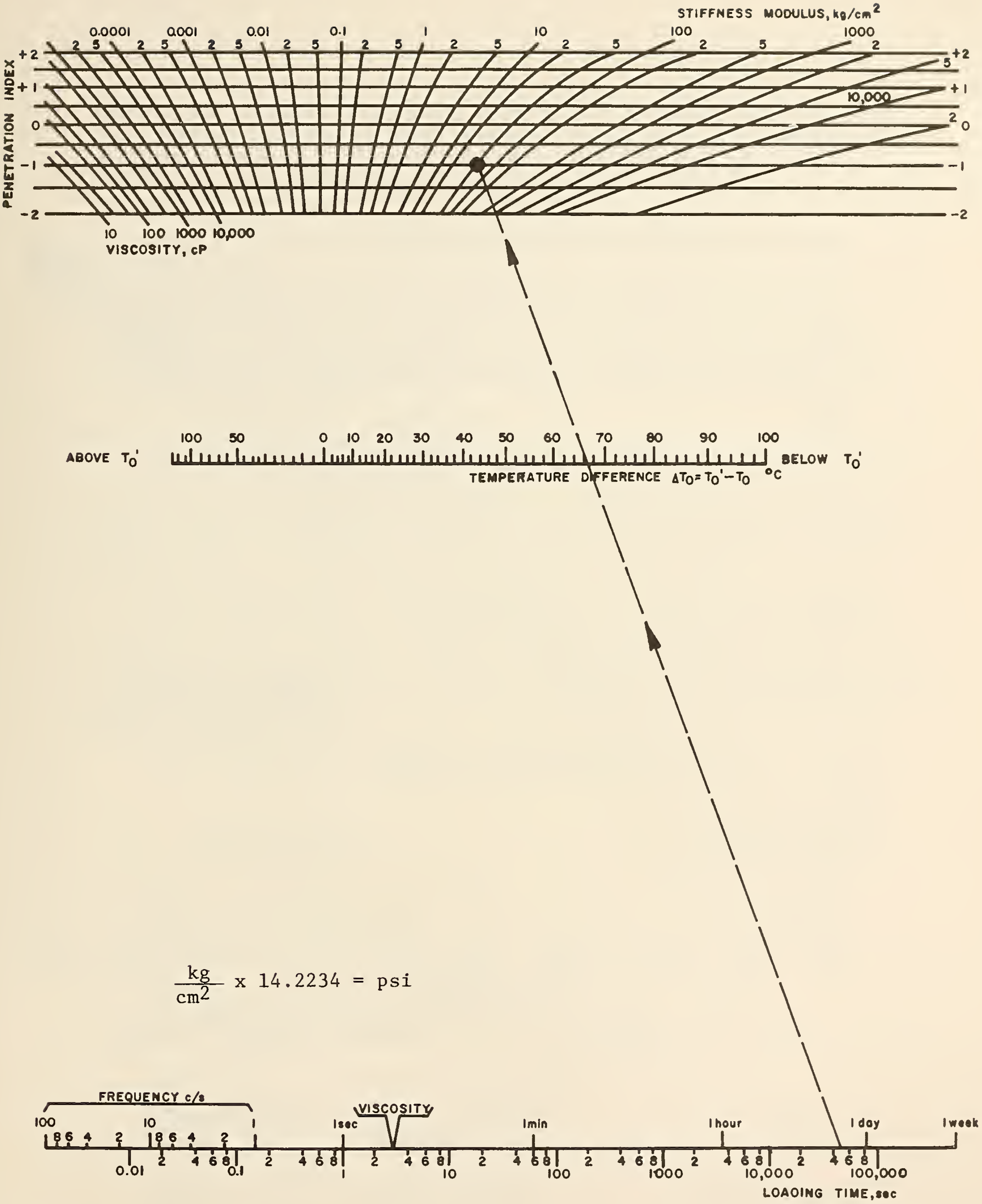


EXAMPLE:

1 Penetration at 25°C (T_{Pen}) = 105 (ASTM D5)
2 Ring and Ball Temp., T_o' (MEASURED) = 43.7°C (ASTM D36)
3 $T_{DIF} = T'_o - T_{Pen} = 43.7^{\circ} - 25^{\circ} = 18.7^{\circ}C$
4 Connect Points 1 and 3
5 P.I. =-1.0

$(^{\circ}C \times 1.8) + 32 = {}^{\circ}F$

Figure 7.5 Nomograph for Determining Pfeiffer and Van Doormaal's Penetration Index (Ref. 12)



$\frac{kg}{cm^2}$ x 14.2234 = psi

Figure 7.6. Nomograph for predicting the stiffness modulus of asphaltic bitumens (after Heukelom and Klomp (Ref. 13).
1^o F = $1.8(^oC)+32^o$

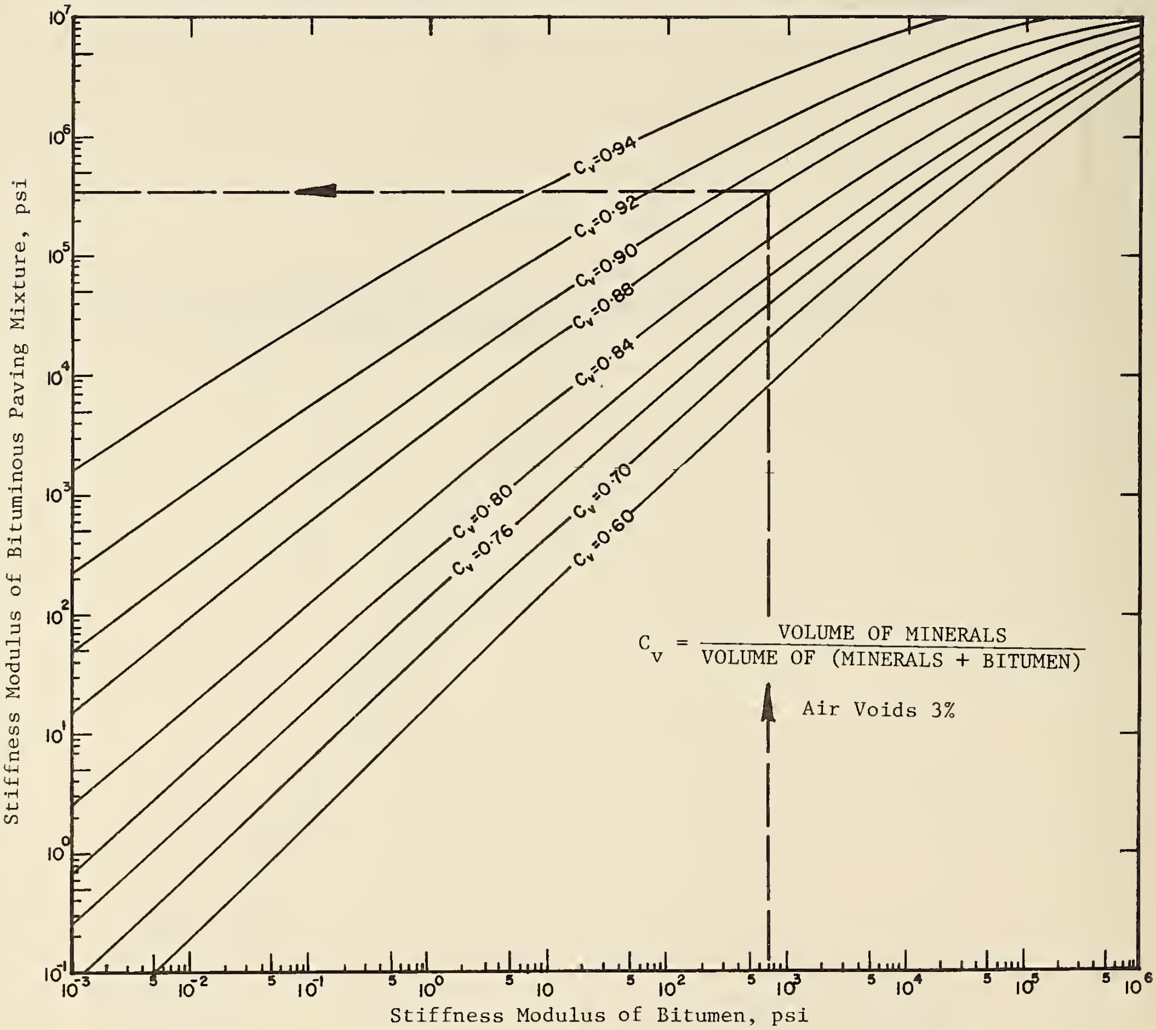


Figure 7.7. Relationships between moduli of stiffness of asphalt cements and of paving mixtures containing the same asphalt cements (Ref. 13).

1 psi=6.9kN/m^2

seconds has normally been used, although the designer may select a 12 hour loading time due to daily temperature cycles. The temperature difference represents the difference between the Ring and Ball test temperature and the minimum temperature expected to occur for the overlay material defined in Section 7.1.9 (T_o).

The stiffness or creep modulus of the bituminous paving mixture can be determined using the relationship presented in Figure 7.7. Entering with the stiffness modulus of the bitumen (Figure 7.6) and projecting to the correct volume concentration of the aggregate (C_v) determines the creep modulus of the asphaltic concrete paving mixture, E_o.

The thickness and Poisson's ratio are as determined for RPOD1. The density of the overlay material is specified by the user based on the mix design. The thermal coefficient of the overlay is dependent on the type of material used. For an asphaltic concrete overlay it is recommended that a value of 1.2×10^{-5} in/in/°F (1 in=2.54cm °C=.5554(°F-32) be used for this coefficient when it is not known directly.

The bonding stress between the overlay and existing pavement is very dependent on overlay type and on the condition of the existing surface. Table 7.6 can be used to estimate the bonding stress. The values in this table were developed in relation to the concrete-to-steel bonding stress, since no information on asphalt over concrete exists.

TABLE 7.6 RECOMMENDED VALUES OF THE ASPHALTIC OVERLAY BONDING STRESS

Condition of Existing Surface	Average Bonding Stress, psi*
1. Smooth: polished surface; no exposed coarse aggregate.	50
2. Rough: Same as for a smooth surface but some of as-constructed texture remains; small amount of coarse aggregate exposed.	500
3. Very Rough: Worn surface with exposed coarse aggregate; contains aggregate popout; contains surface texture.	1200
4. Jagged: Grooves present; numerous aggregate popouts; coarse aggregate highly exposed.	Semi-infinite, ∞

*1 psi=6.9 kN/m^2

Until more information becomes available to determine this value, it is recommended that careful consideration be made when the bonding stress is used. Omitting of the bonding stress assumes that the overlay and existing pavement are totally bonded.

7.1.7 Overlay Reinforcement Properties - The overlay reinforcement properties are dependent on the type of reinforcement used. They are determined in the same manner as previous properties.

7.1.8 Intermediate Layer Properties - When a bond breaker or strain relieving interlayer is used, the total width of this layer is required. The program assumes no force transfer between the overlay and the concrete where such material is used. A material of this type would be a sand layer, unbound granular layer, or any smooth frictionless material. For cushion or intermediate layers the same type properties are required as for the overlay layer.

7.1.9 Design Temperatures - The design temperatures for each layer can be determined by using Figure 7.8 (Ref. 14)[1], which is only applicable to asphalt overlays. If other materials are used to insulate the existing concrete pavement, then the reduction in temperature changes must be obtained from the manufacturer. The design minimum temperature expected to occur over the design period for the overlay, T_o, and intermediate layer, T_2, are average temperatures. The minimum surface or air temperature expected to occur in the design period is estimated from historical records as in the 5-day mean air temperature. From these values and Figure 7.8 the average temperature in each layer can be estimated. The design temperature for the existing concrete pavement, T_c, is the temperature at the bottom of the intermediate or overlay layer.

7.1.10 Design Load - The design load is determined by the user. The width of the design load is based on the wheel configuration considered for design. For a tandem loading condition the width of the design load would be the distance between the outer edges of a set of wheels.

7.2 RFLCR1 Input Guide

An input guide for use of the reflection cracking program RFLCR1 is given in Appendix H.

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[1] Asphalt Overlays and Pavement Rehabilitation, Manual Series No. 17, The Asphalt Institute, November 1969.

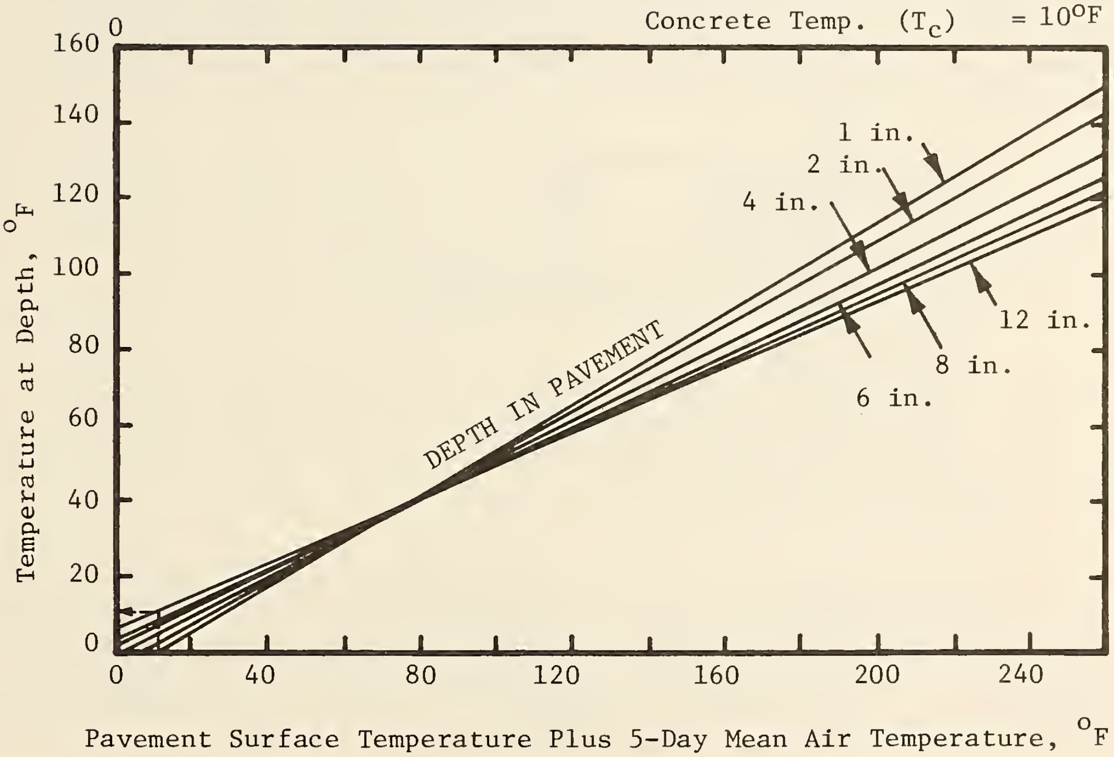
EXAMPLE: 5-Day Mean Air Temp. = 20°F

Min. Surface Temp. = -10°F

10°F

Overlay Thickness (D_o) = 12"

Concrete Temp. (T_c) = 10°F



Note: The 5-Day Mean Air Temperature can be represented by the lowest average weekly temperature obtained from historical records.

Figure 7.8. Predicting pavement temperatures at the bottom of an asphalt overlay (Ref. 14).

$^{\circ}$C=.5554($^{\circ}$F-32)
1 in=2.54cm

SECTION 8

ILLUSTRATIVE OVERLAY DESIGN PROBLEM

This section of the manual presents an overlay design problem that illustrates both the fatigue cracking criterion design and the reflection cracking analysis. It includes example input and resulting output for each of the four computer programs - PLOT2, TVAL2, RPOD1, and RFLCR1. The problem is presented in the following format according to Figure 1.1:

1. Basic design information
2. Condition survey
3. Deflection survey
4. Division of pavement into design sections
5. Classification of existing pavement
6. Determination of material properties
7. Traffic computations
8. Environmental considerations
9. Fatigue cracking analysis and overlay thickness selection
10. Reflection cracking analysis

8.1 Basic Design Information

A 6100 foot (1860.5m) long section of plain jointed concrete pavement on a two lane highway is expected to have a substantial traffic increase in the near future. To handle the anticipated traffic, the decision was made to overlay the pavement with either a bonded jointed concrete overlay or an asphaltic concrete overlay. Designs must be made for each type of overlay in order to make a comparison between the two.

8.2 Condition Survey

The condition survey based on the procedure described in Section 2.2, indicated the pavement is generally in good condition. Spalling, faulting and pumping are minimal and the pavement is fairly smooth. No voids are present beneath the surface. The pavement is built on a uniform fill and has adequate drainage characteristics. The cracking present is class 1 and 2. A review of the construction plans showed the pavement cross section to be as shown in Figure 8.1. Stations 0 to 10 (0 to 305m) have an 8 inch (20.32cm) JCP on a 7 inch (17.78cm) crushed stone base, stations 10 to 52 (305 to 1586m) have an 8 inch (20.32cm) JCP on 6 inches (15.24cm) of gravel base and 6 inches (15.24cm) of granular subbase, and stations 52 to 61 (1586 to 1860.5m) have an 8 inch (20.32cm) JCP on a 7 inch (17.78cm) crushed stone base.

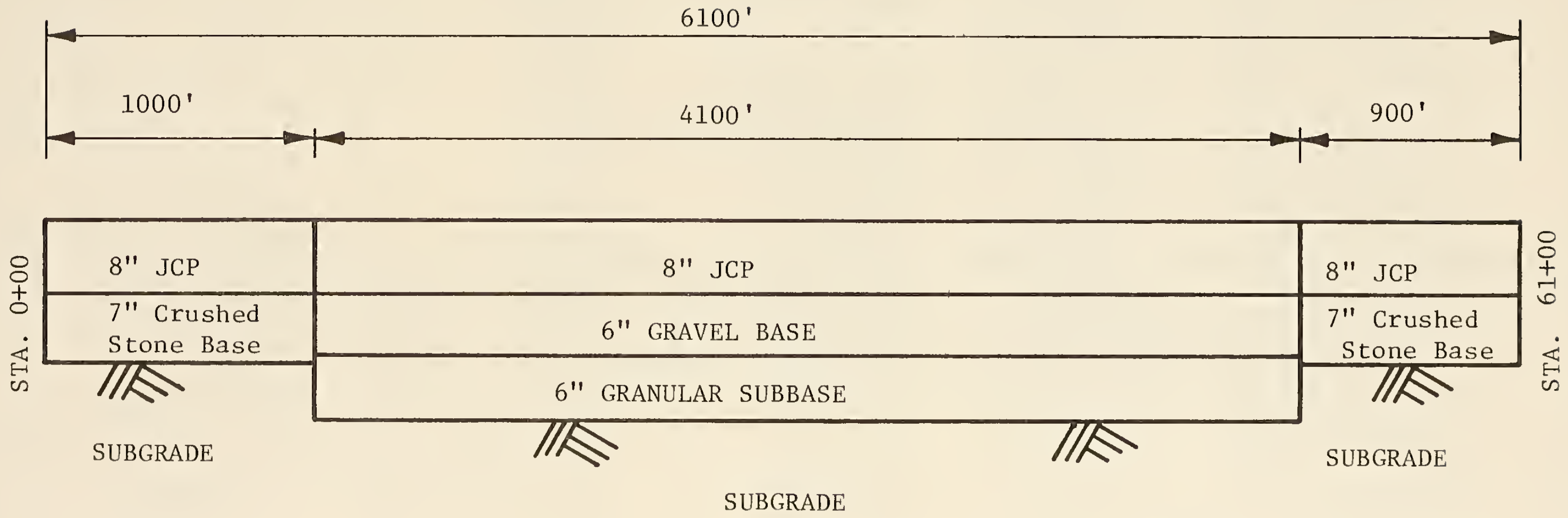


Figure 8.1 Cross section of pavement to be overlaid

1 in=2.54cm
1 station=30.5m
1 ft=.305m

Field data was also collected for use in the reflection cracking analysis for the AC overlay. This data is presented in section 8.10 in the reflection cracking analysis.

8.3 Deflection Survey

The deflection survey, based on the procedure described in Section 2.1, was made with the Dynaflect. The Dynaflect load consists of 500 lbs. (227kg) at 167 psi (1152.3kN/m^2) on each of two wheels spaced 20 inches (50.8cm) apart. Measurements were made in the outside wheel path of each lane at 200 foot (61m) intervals. They were staggered by 100 feet (30.5m) between the two lanes, so that by combining the data a deflection profile could be obtained with measurements each 100 feet (30.5m). These measurements were made in the interior portion of the slabs.

In addition to the interior measurements, deflections were also measured on slab corners at 500 foot (152.5m) intervals. These were made so that the joint condition could be evaluated by computing a ratio of corner deflection to interior deflection. The mean ratio was found to be 1.40, which is indicative of fairly good joint performance.

Deflection measurements were also made at 500 foot (152.5m) intervals to determine the differential joint deflection which is an input to the reflection cracking analysis. The Dynaflect load wheels were placed immediately on one side of the joint and deflections were measured on both the loaded and unloaded sides of the joint. These data are presented in section 8.10 in the reflection cracking analysis.

8.4 Division of Pavement into Design Sections

Both the condition survey and deflection survey are used to divide the pavement into design sections, based on the procedure described in Section 3. Review of the pavement cross section shown in Figure 8.1 indicates that the pavement can be obviously divided into the following three design sections:

Design section 1	Stations 0 to 10	
Design section 2	Stations 10 to 52	
Design section 3	Stations 52 to 61	(1 station=30.5m)

However, to illustrate the use of the programs PLOT2 and TVAL2, the deflection survey data is also analyzed here before final selection of design sections. A plot of the interior deflections measured each 100 feet (30.5m) was made using the computer program PLOT2. The data input for running the program is shown on the input guide in Table 8.1. The resulting deflection profile plot is shown in Figure 8.2. The station number of each measurement location and the actual deflection value plotted are shown on the axes of the plot. The plotted points were connected by hand and the plot was divided by visual inspection into the three design sections shown in the figure. These sections correspond to the sections resulting from the review of the cross section in Figure 8.1.

TABLE 8.1

INPUT DATA FOR PROGRAM PLOT2

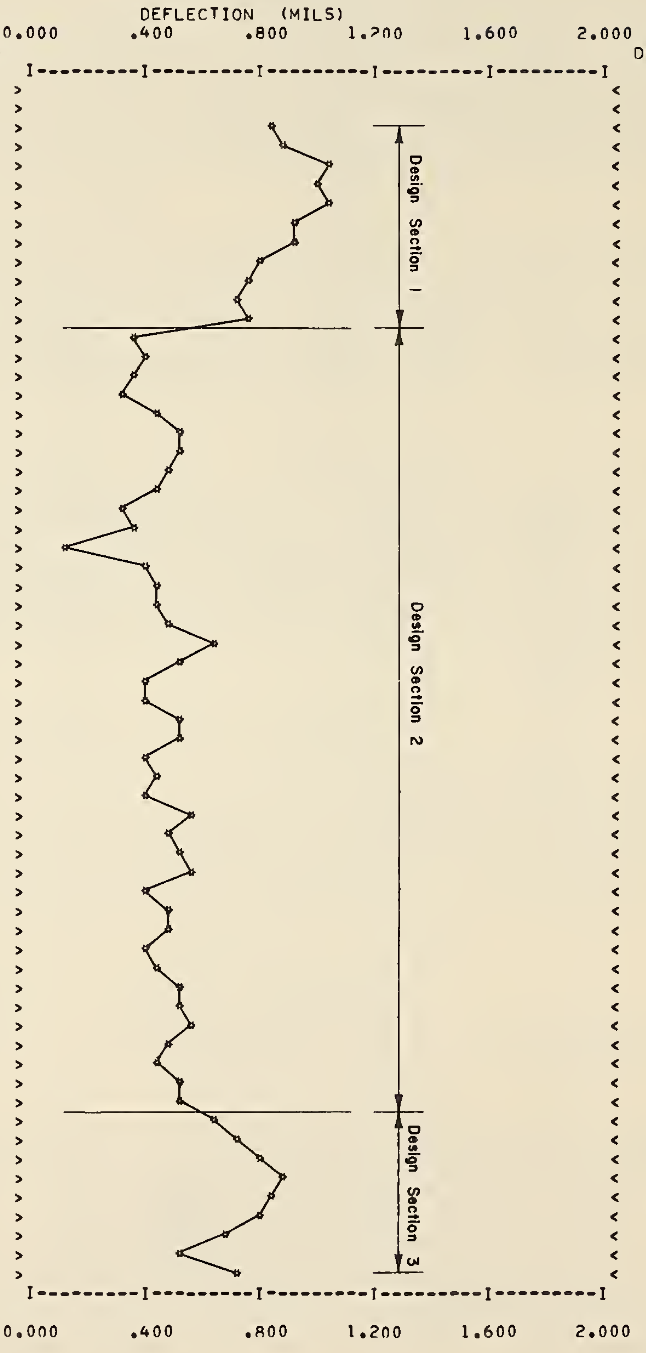
CARD TYPE	1 6 10	15 20	25	30	35 40	45 50	55 60	65 70	75 80
1	☒	ILLUSTRATIVE OVERLAY DESIGN PROBLEM							
2	DYNAFLECT READING - SENSOR 1				STATIONING	(FEET)	DEFLECTION	(MILS)	
3	(2A4,A2,F10.0,F5.0)								
4*	0+10	.86	1.						
5	FINISH								

* A total of 61 cards of this type were included, one for each deflection measurement.

```
PLOT2 - DEFLECTION PLOT PROGRAM, VERSION 2.0

ILLUSTRATIVE OVERLAY DESIGN PROBLEM

                    DYNAFLECT READING - SENSOR 1
```



```
STATIONING                    DEFLECTION
  (FEET)                        (MILS)
   0+10                          .860
   1+10                          .900
   2+10                         1.020
   3+10                          .990
   4+10                         1.020
   5+10                          .930
   6+10                          .920
   7+10                          .800
   8+10                          .760
   9+10                          .740
  10+10                          .750
  11+10                          .370
  12+10                          .400
  13+10                          .370
  14+10                          .340
  15+10                          .450
  16+10                          .520
  17+10                          .500
  18+10                          .460
  19+10                          .450
  20+10                          .310
  21+10                          .350
  22+10                          .132
  23+10                          .400
  24+10                          .440
  25+10                          .440
  26+10                          .490
  27+10                          .640
  28+10                          .510
  29+10                          .390
  30+10                          .400
  31+10                          .540
  32+10                          .500
  33+10                          .420
  34+10                          .440
  35+10                          .380
  36+10                          .580
  37+10                          .460
  38+10                          .540
  39+10                          .560
  40+10                          .400
  41+10                          .460
  42+10                          .470
  43+10                          .420
  44+10                          .440
  45+10                          .510
  46+10                          .510
  47+10                          .580
  48+10                          .460
  49+10                          .440
  50+10                          .510
  51+10                          .530
  52+10                          .640
  53+10                          .720
  54+10                          .790
  55+10                          .880
  56+10                          .860
  57+10                          .800
  58+10                          .680
  59+10                          .540
  60+10                          .720

TOTAL NUMBER OF POINTS PLOTTED =    61
```

FIGURE 8.2. DEFLECTION PROFILE PLOT OF PAVEMENT TO BE OVERLAID

The three sections were then statistically tested using program TVAL2 to see if they are significantly different. The data input to the program is shown in Table 8.3. The resulting output is shown in Table 8.4. The deflections evaluated for each section are listed in order across the page and down. The mean and standard deviation are then printed out. Each section is then compared to each of the other sections to see if they are significantly different. The results show that each comparison failed to pass the "Student's t" test, which means they are significantly different and should be considered as separate design sections.

The last set of output in Table 8.4 is the design deflection for each design section based on a 95 percent confidence level. These same results could be obtained by using equation 3.8 and Table 3.1.

The final design sections selected, based on both the condition survey and deflection analysis, are given in Table 8.2.

TABLE 8.2 FINAL DESIGN SECTIONS

Design Section Number	Station Limits	Design Deflection (mils)
1	0 to 10	1.056
2	10 to 52	.596
3	52 to 61	.915

1 station=3.05m
1 mil=.0025cm

8.5 Classification of Existing Pavement

Each design section must be assigned to one of the overlay design categories described in Section 5. From the condition survey all three sections were found to have Class 1 and 2 cracking as defined in Section 2.2.1. Thus, each design section is assigned to category 1 - pavement with remaining life. The overlay design program RPOD1 will analyze each section as remaining life pavements and compute the amount of remaining life. If it finds that the remaining life is less than the established minimum of 12 percent, it will automatically change the classification from category 1 to category 2.

TABLE 8.3

INPUT DATA FOR PROGRAM TVAL2

CARD TYPE	1 5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
1	61	3	ILLUSTRATIVE OVERLAY DESIGN PROBLEM													
2	11	41	9													
3	95	95	(10X,F10.0,F5.0)													
4*			.86		1.											

*A total of 61 cards of this type were included, one for each deflection measurement.

TABLE 8.4

OUTPUT FROM PROGRAM TVAL2

```
TVAL2 - DEFLECTION SECTION COMPARISON PROGRAM, VERSION 2.0

ILLUSTRATIVE OVERLAY DESIGN PROBLEM

                     DEFLECTIONS FOR EACH SECTION

 SECTION  1            .860        .900       1.020        .990
                      1.020        .930        .920        .800
                       .760        .740        .750

 SECTION  2            .370        .400        .370        .340
                       .450        .520        .500        .460
                       .450        .310        .350        .132
                       .400        .440        .440        .490
                       .640        .510        .390        .400
                       .540        .500        .420        .440
                       .380        .580        .460        .540
                       .560        .400        .460        .470
                       .420        .440        .510        .510
                       .580        .460        .440        .510
                       .530

 SECTION  3            .640        .720        .790        .880
                       .860        .800        .680        .540




                          MEAN           STANDARD DEVIATION

 SECTION  1               .881                 .107

 SECTION  2               .452                 .088

 SECTION  3               .737                 .109




                                                95 P/C
                                              CONF. LEVEL
 SECTION VS. SECTION    DF    CALCULATED T      TABLE T      PASS/FAIL

    1          2        50        13.779         2.011          FAIL

    1          3        18         2.986         2.101          FAIL

    2          3        48         8.464         2.013          FAIL



 DESIGN DEFLECTION CONFIDENCE LEVEL    95.0

      SECTION     INTERIOR DESIGN DEFLECTION

         1                  1.056
         2                   .596
         3                   .915
```

The type of existing pavement is specified as JCP and the types of overlays are specified as bonded JCP and AC. This will key the program to perform analyses 6 and 9 from Figure 1.2.

8.6 Determination of Material Properties

Properties for each material in each design section must be determined according to Section 4. After selection of design sections, a boring plan was established which consisted of the following:

One boring in design section 1
Three borings in design section 2
One boring in design section 3

Cores were obtained from the existing concrete and bulk samples were obtained from the base and subbase materials. Undisturbed tube samples were obtained from the subgrade. Materials for the proposed concrete and AC overlays were obtained from the proper materials sources.

The concrete cores were tested for modulus of elasticity according to Section 4.2.1. The base and subbase samples were recompacted to the estimated in-place moisture and density and tested for modulus of elasticity according to Section 4.3.2. The subgrade samples were tested for resilient modulus of elasticity according to Section 4.4.

Specimens were prepared from the proposed concrete and AC overlay material and tested for modulus of elasticity in accordance with Section 4.2.1. Poisson's Ratio tests were not performed for any of the materials. Values were estimated from those recommended in Section 4.5. Flexural strength of the concrete was determined according to Section 4.2.1.

The resulting material properties are given in Tables 8.5, 8.6 and 8.7. The PCC flexural strength, which is not included in the tables, was found to be 690 psi (4761kN/m^2).

The layer thicknesses of each material determined from the boring logs were in agreement with the construction plan thicknesses determined in the condition survey and shown in Figure 8.1.

TABLE 8.5 MATERIAL PROPERTIES FOR DESIGN SECTION 1

Material Type	Modulus of Elasticity (psi)	Poisson's Ratio
Proposed AC overlay	450,000 @ 70°F	.30
Proposed JCP overlay	4×10^6	.15
Existing JCP	4×10^6	.15
Crushed Stone base	33,000	.35
Subgrade	123,500 @ σ_d * = 3 psi 91,500 @ σ_d = 5 psi 86,400 @ σ_d = 7 psi 69,500 @ σ_d = 9 psi 67,900 @ σ_d =11 psi	.45

*σ_d = deviator stress

TABLE 8.6 MATERIAL PROPERTIES FOR DESIGN SECTION 2

Material Type	Modulus of Elasticity (psi)	Poisson's Ratio
Proposed AC overlay	450,000 @ 70°F	.30
Proposed JCP overlay	4×10^6	.15
Existing JCP	4×10^6	.15
Gravel base	18,000	.35
Granular subbase	12,000	.40
Subgrade	136,200 @ σ_d = 3 psi 73,600 @ σ_d = 5 psi 56,900 @ σ_d = 7 psi 44,000 @ σ_d = 9 psi 32,600 @ σ_d = 11 psi	.45

1 psi=6.9kN/m^2
^{o}C=.5554(^{o}F-32)

TABLE 8.7 MATERIAL PROPERTIES FOR DESIGN SECTION 3

Material Type	Modulus of Elasticity (psi)	Poisson's Ratio
Proposed AC overlay	450,000 @ 70°F	.30
Proposed JCP overlay	4×10^6	.15
Existing JCP	4×10^6	.15
Crushed Stone base	33,000	.35
Subgrade	38,200 @ σ_d = 5 psi	.45
	35,700 @ σ_d = 7 psi	
	31,000 @ σ_d = 9 psi	1 psi=6.9kN/m^2 ^{o}C=.5554(^{o}F-32)

8.7 Traffic Computations

The traffic information necessary for the overlay design is determined according to Section 2.3. The number of equivalent 18- kip (8172kg) single sxle load applications was determined by using equation 2.1 with a directional distribution factor of 0.50 and a lane distribution factor of 1.0 (taken from Table 2.2 for a two lane roadway). The number of actual traffic applications to date were determined as well as three values of projected traffic for different design lives. Results of the traffic computations are given in Table 8.8.

TABLE 8.8 TRAFFIC COMPUTATIONS FOR OVERLAY DESIGN

Equivalent 18-kip (8172kg) single axle load applications to date	300,000
Projected equivalent 18-kip (8172kg) single axle load applications:	
Design life A	2,000,000
Design life B	4,000,000
Design life C	6,000,000

The same traffic information is used in all three design sections.

8.8 Environmental Considerations

The pavement is located in a climate that has no severe temperature or moisture effects that should be given special consideration. The environment was considered in the deflection survey by using the recommended procedure of measuring deflections during the most critical season of the year. In this case the pavement was expected to have the highest deflection in Spring, so this is when the deflections were measured.

8.9 Fatigue Cracking Analysis and Overlay Thickness Selection

The fatigue cracking analysis and resulting overlay thicknesses are determined according to Section 6, through use of the overlay design computer program RPOD1. All of the data necessary to run the program have now been determined. The data input for the AC overlay on design section 1 is shown in Table 8.10. Data were input for the other design sections using the same format.

The output resulting from the computer runs is in Appendix I. Output is included for all six overlay designs that were run; a JCP and an AC overlay for each of the three design sections. The print-out contains two major categories - input variables which consist of (1) existing pavement, (2) deflection data, (3) laboratory tests of subgrade samples, (4) overlay characteristics, and (5) design traffic; and system results which consist of (1) overlay life predictions, (2) a plot of overlay thickness versus fatigue life, and (3) a table of interpolated overlay thicknesses for the requested design fatigue lives.

A summary of the overlay thicknesses for the three design lives is given in Table 8.9.

TABLE 8.9. SUMMARY OF OVERLAY THICKNESSES

Design Section	JCP Overlay (in) Design Life ($x10^6$)			AC Overlay (in) Design Life ($x10^6$)		
	2	4	6	2	4	6
1	3.2	4.8	5.9	7.3	10.0	11.7
2	3.0	4.7	5.7	7.0	9.7	11.4
3	2.3	4.0	5.0	5.8	8.6	10.2

1 in=2.54cm

A comparison can now be made between the JCP and AC overlays and the desired one can be chosen for construction. Since there is a considerable difference in the JCP and AC thicknesses, material availability and costs as well as construction costs would be key decision factors in choosing the overlay type. Assuming that JCP materials cost only slightly more than AC materials for the area where this overlay is to be constructed, the JCP overlay is preferable to the AC overlay. It may be most desirable, from a construction feasibility viewpoint, to construct a 6 inch (15.2cm) overlay. This would provide a design life of slightly greater than 6 x 10^6 18-kip (8172kg) SAWL, as shown by the overlay design solutions. Thus, the final overlay design is selected to be a 6 inch (15.2cm) bonded JCP.

TABLE 8.10

INPUT DATA FOR JCP OVERLAY ON DESIGN SECTION 1

CARD TYPE	1 … 8	10	20	25	30	34	38	40	50	60	70	80
1	PROBLEM	1	1									
2	ILLUSTRATIVE OVERLAY DESIGN PROBLEM, SECTION 1.											
3	PAVEMENT	3	300000.	690.	☒	TYPE 1,2						
4	LAYER	1	4000000.	8.	.15	JCP						
4	LAYER	2	33000.	7.	.35	GRAN						
4	LAYER	3	50000.	0.	.45	SUBG						
5	LOADS	2	500.	167.								
6	0.		0.	20.		0.						
7	DEFLECT	☒	.001056	10.	0.							
8	LAB DATA	5										
9	123500.		3.	91500.		5.			86400.	7.	69500.	9.
9	67900.		11.									
10	OVERLAY	☒	4000000.	.15	☒	JCP	BOND					
12	CORNER	☒	1.4									
13	TRAFFIC	3										
14	2000000.		4000000.	6000000.								
15	END											

8.10 Reflection Cracking Analysis

The AC overlay alternate is analyzed for reflection cracking according to Section 7 of this manual. The jointed concrete overlay is not analyzed for reflection cracks because joints will be matched and cracking is not a problem in the existing concrete pavement.

8.10.1 Existing Pavement Properties - From the condition survey, it was observed that only a small amount of cracking was present; therefore a joint spacing of 20 feet (6.1m) is used in the computer program RFLCR1. In evaluating joints measured, the steel reinforcement card is left blank.

Modulus, Poisson's ratio and thickness are as determined for RPOD1. Density is determined from cores taken during materials sampling and represents an average value. The thermal coefficient of concrete and the movement at which sliding occurs were not tested for but estimated using Tables 7.1 and 7.2, respectively. From the materials sampling, a granular subbase was found to exist in all design sections. Therefore, in accordance with Section 7.1.3, the increase in overburden pressure will be applied by the program (IFSLOPE>0). Table 8.11 summarizes the existing pavement properties required for evaluating the jointed concrete pavement.

TABLE 8.11 SUMMARY OF EXISTING
PAVEMENT PROPERTIES

Variable	Value
Joint Spacing	20 ft.(6.1m)
Modulus	4,000,000 psi (276,000,000kN/m^2)
Thickness	8 in. (20.3cm)
Density	148 pcf (2368kg/m^3)
Thermal Coefficient	.000006 in./in./°F (cm/°C)
Movement at Sliding	0.25 in. (6.35cm)

8.10.2 Characterization Measurements - Horizontal and vertical characterization measurements are taken during the condition and deflection surveys. This data is presented in Tables 8.12 and 8.13. The minimum temperature experienced by the existing pavement is discussed in Section 8.10.4.

An evaluation of the horizontal movements (Table 8.12) is graphically illustrated in Figure 8.2. A 90% design level was selected, which results in a joint movement of 0.0183 inches (.046cm) (Figure 8.2.a). This joint movement corresponds to a maximum joint width of 0.208 inches (.528cm) at 73°F (22.7°C) and a minimum joint width of 0.1897 inches (.48cm) at 95°F (33.9°C) (Figure 8.2.b).

Table 8.12. Measurement of Horizontal Movements for Reflection Cracking Analysis

HORIZONTAL MOVEMENTS

Job: Illustrative overlay design problem

Description: Plain Jointed Concrete Pavement

Measurement Device: Microscope

Measurement Number or Location	Joint Spacing, Ft.	Air Temperature ^oF	Joint Width in.	Air Temperature ^oF	Joint Width in.	Temperature Change ^oF	Joint Movement, in.
STA. 0	20	70	0.200	90	0.185	20	.015
5	20	70	0.203	91	0.189	21	.014
10	20	71	0.192	92	0.177	21	.015
15	20	72	0.198	93	0.180	21	.018
20	20	72	0.210	94	0.191	22	.019
25	20	73	0.186	94	0.171	21	.015
30	20	74	0.195	95	0.179	21	.016
35	20	74	0.182	95	0.164	21	.018
40	20	74	0.196	96	0.179	22	.017
45	20	75	0.192	97	0.176	22	.016
50	20	75	0.189	98	0.174	23	.015
55	20	76	0.199	98	0.180	22	.019
60	20	76	0.194	99	0.177	23	.017
Mean Temp.		73		95		22	

1 ft=.305m

$^oC=.5554(^oF-32)$

1 in=2.54cm

1 station=30.5m

Table 8.13. Measurement of vertical movements for Reflection Cracking Analysis

VERTICAL MOVEMENTS

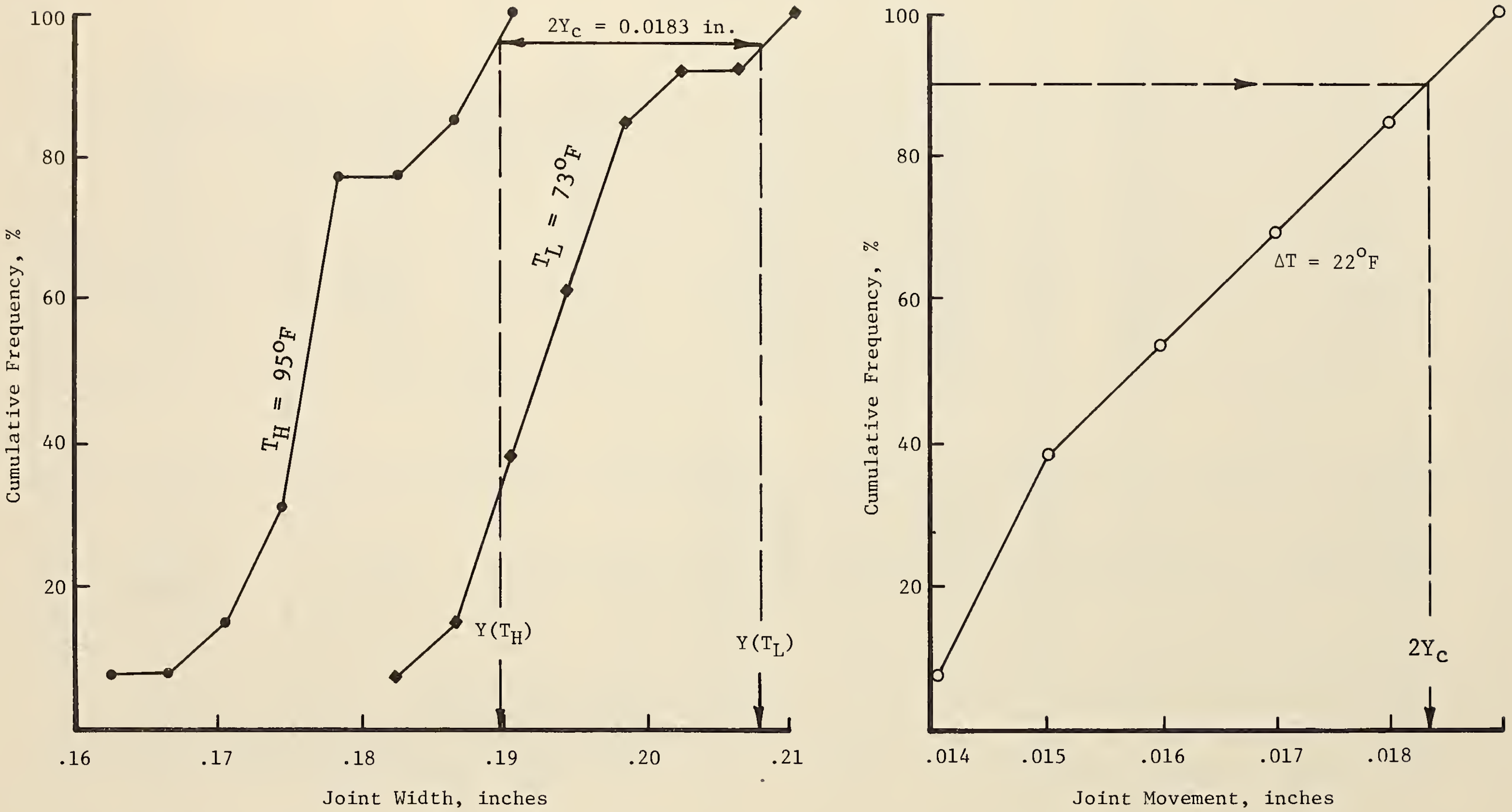
Job: Illustrative overlay design problem

Description: Plain Jointed Concrete Pavement

Measurement Device: Dynaflect (Sensors 1 and 2)

Measurement or Location	Joint Width, in.	Temperature, ^{o}F	Deflection, inches		Differential Deflection in.	Percent Load Transfer, %
			Loaded Joint	Unloaded Joint		
STA. 0	.191	85	.0040	.0036	.0004	90.0
5	.193	86	.0062	.0055	.0007	88.7
10	.188	86	.0068	.0055	.0013	80.9
15	.186	88	.0065	.0060	.0005	92.3
20	.183	89	.0075	.0035	.0040	46.7
25	.187	89	.0067	.0063	.0004	94.0
30	.192	90	.0061	.0052	.0009	85.2
35	.184	91	.0053	.0042	.0011	79.2
40	.190	91	.0054	.0050	.0004	92.6
45	.186	92	.0045	.0039	.0006	86.7
50	.183	92	.0043	.0038	.0005	88.4
55	.178	92	.0039	.0035	.0004	89.7
60	.180	94	.0037	.0030	.0007	81.1

1 in=2.54cm
$^{o}C=.5554(^{o}F-32)$
1 station=30.5m



(a.) Estimation of maximum joint widths for design.

(b.) Evaluation of joint movements.

Figure 8.2 Determination of the horizontal characterization inputs for the program RFLCR1.

1 in=2.54cm
°C=.5554(°F-32)

A Dynaflect was used to measure deflections at loaded and unloaded joints (Table 8.13). An evaluation of this data is graphically illustrated in Figure 8.3. A 90% design level was selected, which results in a percent load transfer of 78% for a mean joint width of 0.19 inches (.482cm). No test data is available to determine if the percent load transfer will vary with season or with heavier loads; therefore, the value estimated from Figure 8.3 is input into the program.

8.10.3 Overlay Properties - The dynamic modulus, Poisson's ratio and thickness are as determined for and by RPOD1. Since no laboratory test data exists for determining the creep modulus, it is estimated using the example presented in Figures 7.5-7.7. The selected mix design was determined to have a ring and ball temperature of 43.7°C (ASTM D36) and a penetration of 10.5mm at 25°C (ASTMD5). The temperature difference in Figure 7.6 will be discussed in Section 8.10.4.

The thermal coefficient of the AC overlay was selected in accordance with Section 7.1.6, due to an absence of test values. The bonding stress between the overlay and existing pavement was taken from Table 7.6. During the condition survey it was observed that some of the as-constructed texture remains; hence a value of 500 psi (3450kN/m^2) was selected. The density of the AC overlay was specified by the designer to be 140 pcf (8.74kg/m^3). No reinforcement or intermediate layers were chosen for the design, therefore these cards are left blank. A 1/8 inch (.32cm) layer of sand was specified to act as a bond breaker across the joints with variable width. Table 8.14 summarizes the overlay properties needed for evaluating the proposed overlay design.

TABLE 8.14 SUMMARY OF OVERLAY PROPERTIES

Variable	Value
Creep Modulus	350,000 psi
Dynamic Modulus	4,000,000 psi
Thickness	10.4, 12.0 in.
Density	140 pcf
Poisson's Ratio	0.3
Thermal Coefficient	.000012 in./in./°F
Bonding Stress	500 psi

1 psi=6.9kN/m^2
1 in=2.54cm
°C=.5554(°F-32)

8.10.4 Other Design Inputs - From past temperature data it was found that a minimum temperature experienced by the existing pavement was -20°F (-28.9°C), and is predicted that a -10°F (23.3°C) will occur in the design period. A 5-day mean air temperature of 20°F (6.7°C) was also obtained from the historical records. With this data, Figure 7.8 can be used to determine the design temperature for the existing pavement (10°F or -12.2°C). It is estimated that the temperature of the slab after overlay placement will be 110°F (43.3°C), hence the design temperature difference for the existing

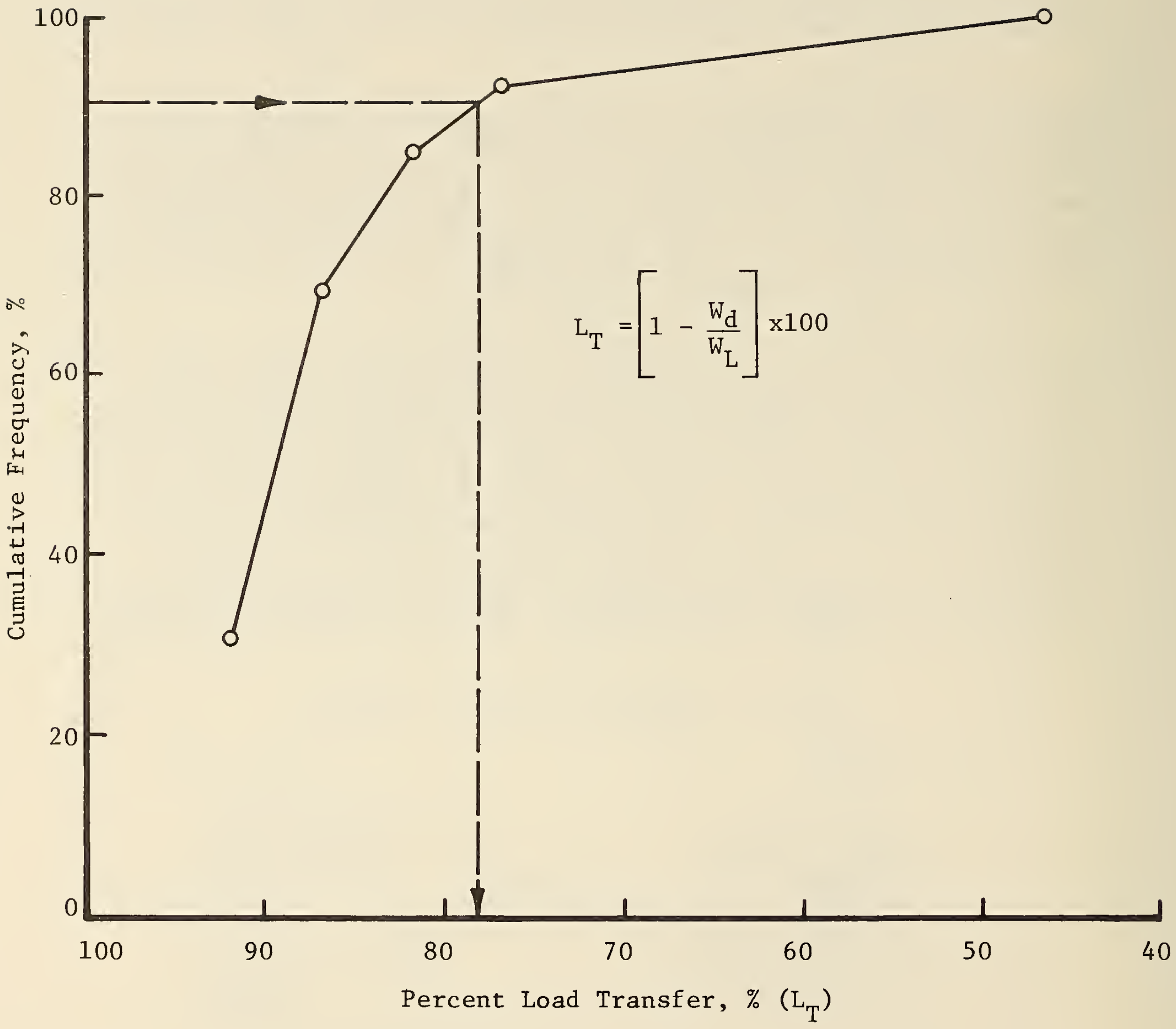


Figure 8.3. Determination of the vertical characterization inputs for the program RFLCR1.

pavement is 100°F (37.8°C). For a conservative estimate the average temperature of the overlay was taken to be the minimum surface temperature, resulting in a design temperature change of 120°F (48.9°C). $(T_o' - T_o)$.

From traffic data if it expected that a 24-kip (10896kg) axle load will use the highway being overlayed. Using a wheel load configuration of the 24-kip (10896kg) axle load, the design load width is estimated to be 24 inches (61.0cm). A summary of the other design inputs is given in Table 8.15.

TABLE 8.15 SUMMARY OF OTHER DESIGN INPUTS

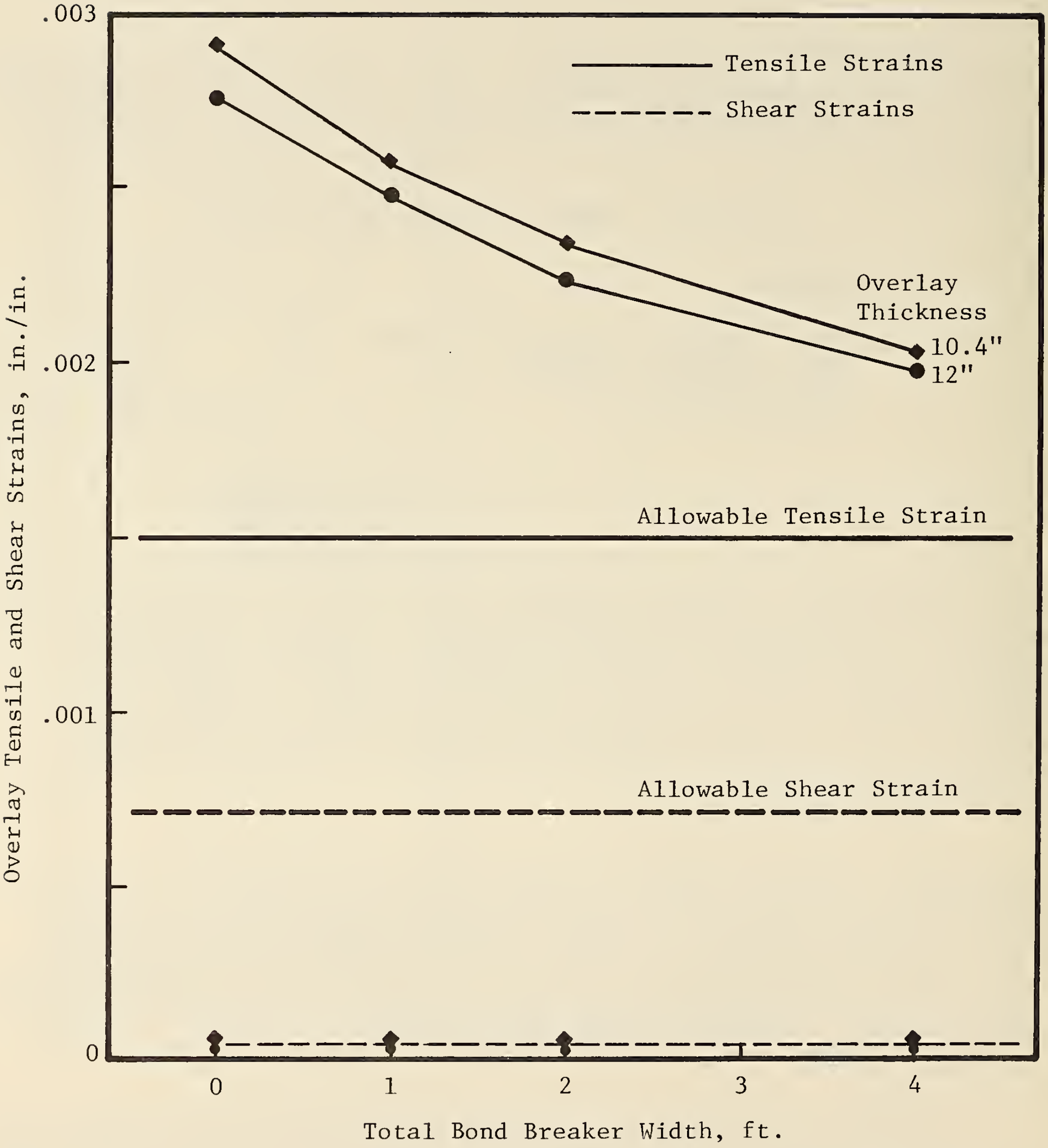
Variable	Value
Temp. Change of Existing Pavement	100°F
Temp. Change of Overlay	120°F
Design Load	24,000 lbs.
Design Load Width	24 in.

°C=.5554(°F-32)
1 lb.=.454kg
1 in=2.54cm

8.10.5 Reflection Cracking Evaluation - The reflection cracking analysis is determined according to Section 7 through the use of the computer program RFLCR1. All data necessary to run the problem has been determined. The data input for the AC overlay alternate for design section 1 (12 in. (30.5cm) overlay) is shown in Table 8.16. Data input for the other design section (10.4 in. (26.4cm) overlay) used the same format.

The output resulting from the computer runs is presented in Appendix J. Output is only included for design section 1. The printout contains two major categories - input variables which consist of (1) existing pavement properties, (2) characterization measurements, (3) overlay properties, and (4) other design inputs; and system results which consist of (1) Beta values (restraint coefficients), (2) slope of the friction curve, (3) stresses in the existing pavement, and (4) overlay strains.

A summary of the results are graphically illustrated in Figure 8.4. By comparing the tensile and shearing strengths of the overlay material, determined using the procedure given in Appendix K, with the tensile and shearing strains computed with RFLCR1 will determine if reflection cracks will develop. As can be observed in Figure 8.4, reflection cracks will develop for the design conditions considered. Therefore some other AC overlay design must be considered or the concrete overlay alternate must be used if reflection cracks are not to occur.



1 in=2.54cm
1 ft=.305m

Figure 8.4. Graphical illustration of the resulting tensile and shear strains computed with RFLCR1.

TABLE 8.16. Input Data for AC Overlay for the Program RFLCR1

CARD TYPE	1–10	20	30	40	50	60	70	80
1	ILLUSTRATIVE EXAMPLE PROBLEM							
2	ASPHALTIC CONCRETE OVERLAY W/BOND BREAKER ON JOINTED CONC. PAVT.							
3	JCP U	4000000.0	.000006	8.0	148.0	20.0	0.25	
4	STEEL							
5	HORIZ CHAR	95.0	.1897	73.0	.2080	-20.0		
6	VERT CHAR	0.19	0.78					
7	AC	350000	.000012	12.0	140.0	0.30	4000000.0	500.0
8	OVRTYP							
9	BOND BKR							
10	INTER LAYR							
11	DESIGN	100.0		120.0	24000.0	24.0		
12	SLOPE SWCH	1.0						
13	PART							
14	350000	4000000	12.0	1.0	100.0		120.0	1.0
15	PART							
16	350000	4000000	12.0	2.0	100.0		120.0	1.0
17	PART							
18	350000	4000000	12.0	4.0	100.0		120.0	1.0
19	STOP							

APPENDIX A

CONDITION SURVEY TECHNIQUES

The condition survey techniques outlined in the following paragraphs should be used in conjunction with the overlay design procedure outlined in the text of this design manual. The following paragraphs will relate specifically to the timing of condition surveys, the essential data required in the design analysis, a format for recording data, and a procedure for reduction of the data for the design analysis.

TIMING OF CONDITION SURVEYS

Normally, condition surveys should be done when convenient to the project engineer and still provide current information. Condition surveys made at the time of nondestructive testing accomplishes two purposes. Distress observed in the field can be recorded directly with deflection measurements, and if detours or lane closure is required the survey crews are protected. Thus, less closure time results which is important relative to freeway operations.

ESSENTIAL DATA

The essential condition survey data for the overlay design analysis is an inventory of the class of cracking present on the existing concrete pavement. A general assessment of the drainage, joint condition, faulting, spalling, pumping, and other factors might help to explain variation in a deflection profile. These elements of data will all be useful in the overlay design analysis. Specifically, the classification of cracking is the only decision factor necessary in the overlay design procedure. The drainage, grade, and other data are simply additional information which will enable an engineer to quantitatively evaluate variation he observes in deflection profiles and subsequent material tests from laboratory work. The drainage data also serve as input to the consideration of tradeoffs between overlay thickness and drainage improvements. In some design situations it may be possible to improve drainage which will in turn improve material properties and result in less overlay thickness. Economic comparisons should be made between the two.

FORMAT FOR RECORDING DATA

There are several ways to conveniently record condition survey data and an agency may want to use its experience to develop forms.

TABLE A.1

SAMPLE CONDITION SURVEY DATA FORM

County ______________

Highway ______________

Date ______________

Stations		Cracking					Faulting	Spalling	Pumping	Drainage		Grade			OTHER COMMENTS
From	To	Uncr.	Cl. 1	Cl. 2	Cl. 3	Cl. 4				Good	Poor	Cut	Fill	Natural	

If condition surveys are made at the time of deflection measurements, these data may be recorded on the same data sheet using the same identification as the deflection measurement, for example, station numbers. A suggested format for recording data is shown in Table A.1, where the station limits are selected as base elements, normally one hundred feet. The various columns in the table should be either checked for the presence of the conditions or actual measurements such as faulting, spalling, pumping, etc., should be filled in.

Data may also be recorded on other types of records such as plan profiles with some information relative to the existing pavements, on soil profiles or any other existing information sheets for the pavement. Every opportunity should be taken to include existing data for the pavements where possible.

DATA REDUCTION FOR DESIGN

The pavement condition should be classified according to its general type of cracking and should fit into one of the following classes:

1. Uncracked or class 1 and 2 cracking
2. Class 3 and 4 cracking
3. Severely enough cracked that the pavement should be mechanically broken up into small pieces.

The classification chosen determines the overlay analysis procedure that will be used. If voids exist beneath the pavement this must be recorded also.

APPENDIX B

PLOT2 DESCRIPTION AND INPUT GUIDE

BACKGROUND

Program PLOT2 was written to make a printer plot of deflections vs. distance along the roadway, deflection being represented by the Y-value of the graph and distance being represented by the X-value. However, the program allows any two-dimensional graph to be plotted when given the X value and corresponding Y value of the function by changing the labels for the axes from static constants to variables which are used in with the data (see input guide from PLOT2).

DATA INPUT

The input for PLOT2 consists primarily of title heading, labels for the lists of X and Y values, X and Y axis labels, and a data card for each X - Y value pair (maximum of 300 X - Y value cards). Each X - Y value card also contains a multiplication factor for the Y value. The multiplication factor allows the user to input direct Dynaflect measurements. The program will convert these measurements to deflections using the multiplication factor for the Dynaflect measuring device. If the measurements have already been converted this factor may be left blank and the program will use a default value of 1.

A more detailed explanation of PLOT2 input can be found in the input guide in Table B.1.

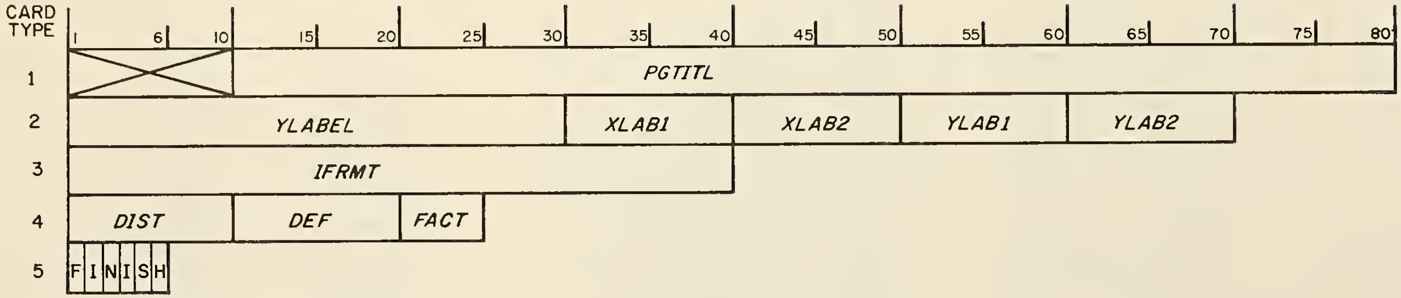
OUTPUT

Program PLOT2 generates a line printer plot in which only the Y or horizontal axis is scaled. The X-axis is not scaled so that regardless of deflection location, they are plotted on consecutive lines down the page with the coordinates of each point printed on either side of the plot.

The program will also count and print the number of X - Y value cards submitted. This number can then be used when submitting the same data with program TVAL2 whose input data must include the number of deflections.

TABLE B.1

INPUT GUIDE FOR PLOT2



Card Type 1: Problem Title Card
PGTITL = Title for this problem. (Col. 11-80, alphanumeric)

Card Type 2: Plot Label Card
YLABEL = General label for deflection axis of the plot. Default value is "DYNAFLECT READING, SENSOR 1." (Col. 1-30, alphanumeric)
XLAB1 = First row label for list of deflection locations. Default is "STATIONING." (Col. 31-40, alphanumeric)
XLAB2 = Second row label for list of deflection locations. Default is "(FEET)." (Col. 41-50, alphanumeric)
YLAB1 = First row label for list of deflection values. Default is "DEFLECTION." (Col. 51-60, alphanumeric)
YLAB2 = Second row label for list of deflection values. Default is "(MILS)."

Note that it is useful to center each label in its field and that the second row labels are useful for specifying units.

Card Type 3: Deflection Format Card
IFRMT = Format for reading in the deflection data. Default is "(2A4,A2,F10.0,F5.0)" where the first 10 columns (2A4,A2) are for reading the deflection location or station, the next 10 columns (F10.0) are for reading the actual deflection and the last 5 columns, (F5.0) are for reading the deflection multiplier.

Card Type 4: Deflection Data Card

This card type is used to read the deflection data. A maximum of 300 deflections can be read and plotted.

Through the use of IFRMT in Card Type 3, it is possible for the user to specify the format in which he wishes to read this data. The user cannot, however, change the order in which the deflection and its multiplier are read. The deflection value (DEF) must be read first and the multiplier (FACT) last.

If the user does not specify an input format, the data will be read as follows:

DIST = Location where deflection measurement was taken. (Col. 1-10), alphanumeric)
DEF = Deflection value. (Col. 11-20, real)
FACT = Deflection multiplication factor. Default value is 1. (Col. 21-25, real)

Card Type 5: Termination Card

To designate the end of the data, the user must have "Finish in the first seven columns of the field in which the deflection location is read. If the default format for reading the deflection data was used, this would mean in Columns 1-7.

APPENDIX C

TVAL2 DESCRIPTION AND INPUT GUIDE

BACKGROUND

The purpose of program TVAL2 is to determine whether the mean deflection measurements for the different user specified roadway sections differ significantly using a Student's t analysis. The program will also compute the interior design deflection for each section if the user specifies some minimum confidence level. The procedure and tables used for the Student's t analysis in this program were taken from Introduction to Probability and Statistics, 3rd Edition, Alder and Roessler, W. H. Freeman and Co.

DATA INPUT

Inputs to the program include an alphanumeric title for each run, the total number of deflection measuremnts taken along the roadway, the number of sections into which these deflections have been separated, the number of deflections in each section, the individual deflection values themselves*, and the confidence levels for both the Student's t analysis and the design deflection determination.

A more detailed description of the data input can be found in the TVAL2 Input Guide in Table C.1.

DESCRIPTION OF STUDENT'S T ANALYSIS

In order to determine whether the means of two sections differ significantly using the Student's t analysis, it is necessary to assume that the standard deviations for each section do not differ significantly. The hypothesis is made that the means of the two sections being compared are the same. The ensuing calculations then determine whether this hypothesis is true or false. Before describing the equations used to make these calculations and those to determine the design deflection, it is useful to define the parameters, variables and subscripts that are used in them.

---

*Note that the default format for the deflection value cards for TVAL2 is the same as that for PLOT2.

j = subscript referring to the j^{th} section
k = subscript referring to the section being tested against the j^{th} section
M = total number of sections
x_i = i^{th} deflection (in j^{th} section)
N_j = total number of deflections in j^{th} section
$\bar{x}_j$ = mean deflection for j^{th} section
σ_j = standard deviation for j^{th} section
D_j = sum of the differences squared between the mean and the i^{th} deflection for each section
υ = number of degrees of freedom for the j^{th} versus k^{th} section combination
s_{jk} = pooled estimate of the standard deviation for the j^{th} versus k^{th} section combination
t = Student's t value calculated
T = minimum Student's t value required for hypothesis to be true (from table of degrees of freedom versus specified minimum confidence level)
$\propto$ = specified minimum confidence level for determining design deflection
z = number of standard deviations beyond the section mean required to achieve the specified minimum confidence level
$x_{\propto j}$ = design deflection for j^{th} section

The following equations are used to determine if the hypothesis is true:

$$\bar{x}_j = \frac{\sum_{i=1}^{N_j} x_i}{N_j} \quad \text{. . . . .} \quad (C.1)$$

$$D_j = \sum_{i=1}^{N_j} (x_i - \bar{x}_j)^2 \quad \text{. . . . .} \quad (C.2)$$

$$\upsilon = N_j + N_k - 2 \quad \text{. . . . .} \quad (C.3)$$

$$s_{jk} = \sqrt{\frac{D_j + D_k}{N_j + N_k - 2}} \quad \text{. . . . .} \quad (C.4)$$

and

$$t = \frac{(\bar{x}_j - \bar{x}_k)}{s_{jk}\sqrt{\frac{1}{N_j} + \frac{1}{N_k}}} \quad \ldots\ldots\ldots\ldots\ldots \quad (C.5)$$

Since, however, the hypothesis was made that the means of the two sections were equal, Equation C.5 reduces to

$$t = \frac{\bar{x}_j - \bar{x}_k}{s_{jk}\sqrt{\frac{1}{N_j} + \frac{1}{N_k}}} \quad \ldots\ldots\ldots\ldots\ldots \quad (C.6)$$

If it is determined that this calculated t value is less than T, the table t value, then the hypothesis that the two section means do not differ significantly is true* or they "PASS" the test. Conversely, if the calculated t is greater than the table t, then the hypothesis is false and the two section menas do differ significantly or the "FAIL" the test.

Equations C.1, C.2, and the following are used to determine the design deflection for each section.

$$\sigma_j = \sqrt{\frac{D_j}{N_j - 1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (C.7)$$

$$x_{\alpha j} = \bar{x}_j + (z.\sigma_j) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (C.8)$$

OUTPUT

Program TVAL2 output consists of the deflections as they were grouped in each section, the mean and standard deviation for each section, a table of the results of the Student's t analysis for all possible combinations of sections taken two at a time, and finally the computed design deflection for each section.

---

*Note: Since the purpose of the overall procedure is to select sections with significantly different mean deflections, so as to produce significantly different overlay designs for each section, the user should consider combining any sections whose means do not differ significantly and then re-run TVAL2.

TABLE C.1

INPUT GUIDE FOR TVAL2

CARD TYPE	1 5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
1	NDEF	NSEC	TITLE													
2	NX1	NX2	NX3	NX4	NX5	NX6	NX7	NX8	NX9	NX10	NX11	NX12	NX13	NX14	NX15	NX16
3	ICL	CL	IFRMT													
4	☒		DEF		FACT											

Card Type 1: Problem Description Card

NDEF = Total number of deflections to be read. (Col. 1-5, integer, right justify)

NSEC = Number of sections into which deflections are divided. (Col. 6-10, integer, right justify)

TITLE = Problem title; it is useful to specify the deflection units here also. (Col. 11-80, alphanumeric)

Card Type 2: Section Specification Card

NX1 = Number of deflections in section 1. (Col. 1-5, integer, right justify)

NX2 = Number of deflections in section 2. (Col. 1-6, integer, right justify)

NX_i = Number of deflections in section i, etc. (Maximum of 16 sections)

Card Type 3: Confidence Level and Deflection Format Card

ICL = Confidence level for Student's t analysis. Permitted values are: 90, 95, and 99 percent, default value (if left blank) is 95 percent. (Col. 1-5, integer, right justify)

CL = Confidence level for computing interior design deflection. Permitted values are: 99, 97.5, 95, 90, 75, and 50 percent. Leave blank if this option is not desired. (Col. 6-10, real)

IFRMT = Format for reading in the deflection data. (Col. 1-40, alphanumeric. Note that this format must include open and close parentheses. Default is (10X,F10.0,F5.0), where the 10X field designates that the first 10 columns of the card are skipped, the F10.0 field is for reading in the deflection and the F5.0 field is for reading in its multiplier)

Card Type 4: Deflection Data Card

This card type is used to read in the deflection data. A maximum of 1440 deflection values (16 sections at 90 per section) is allowed.

Through the use of IFRMT in Card Type 3, it is possible for the user to specify the format in which he wishes to read this data. The user cannot, however, change the order in which the deflection and its multiplier are read. The deflection value (DEF) must be read first and the multiplier (FACT) last.

If the user does not specify an input format, the data will be read as follows:

DEF = Deflection value. (Col. 11-20, real. Note that columns 1-10 are skipped as they may contain data such as the location of the deflection which is not required for the Student's t analysis).

FACT = Deflection multiplication factor. Default value is 1. (Col. 21-25, real)

APPENDIX D

TEST PROCEDURE FOR DYNAMIC MODULUS OF ASPHALT CONCRETE

APPARATUS

1. Test machine - the two types of equipment capable of producing one or more of the load pulses required are electro-hydraulic testing machines with function generators and pneumatic machines with fluidic timers. The former is readily available from well known sources and much more expensive, but has flexibility in shapes of pulses that may be generated. The latter is limited to square pulses, but is much less expensive, simple to operate and almost maintenance free. The pneumatic machine is basically of the type developed by Seed and others (Ref. 15)[1] for resilient modulus testing of soils, but a larger loading piston is used to produce the load required for asphaltic concrete specimens. A photograph of the testing machine is shown in Figure D.1.

2. Strain measurement system - both LVDT's (Linear Variable Differential Transformers) and strain gauges have been used successfully.

The LVDT's are usually used in pairs on the opposite sides of the sample measuring vertical movement between two horizontal clamps firmly attached to the sample (See Figure D.1). The LVDT transducers are attached to one clamp, and rods that can be screwed in or out for zeroing to the other with the LVDT cores on the opposite end fitting into the transducers. Change in sample length between the clamps will result in an increase in voltage output through the transducer and a calibrated trace on a strip recorder's chart paper.

Wire strain gauges are also used in pairs bonded at mid-height on opposite sides of the specimen. The gauges are wired in a Wheatstone bridge circuit with two active gages on the test specimen and two temperature compensating gauges similarly bonded on an unstressed specimen exposed to the same environment as the test specimen.

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[1] Seeds, H. B., F. G. Mitry, C. L. Monismith, and C. K. Chan, Prediction of Flexible Pavement Deflection for Laboratory Repeated Load Test, NCHRP Report No. 35, 1967.

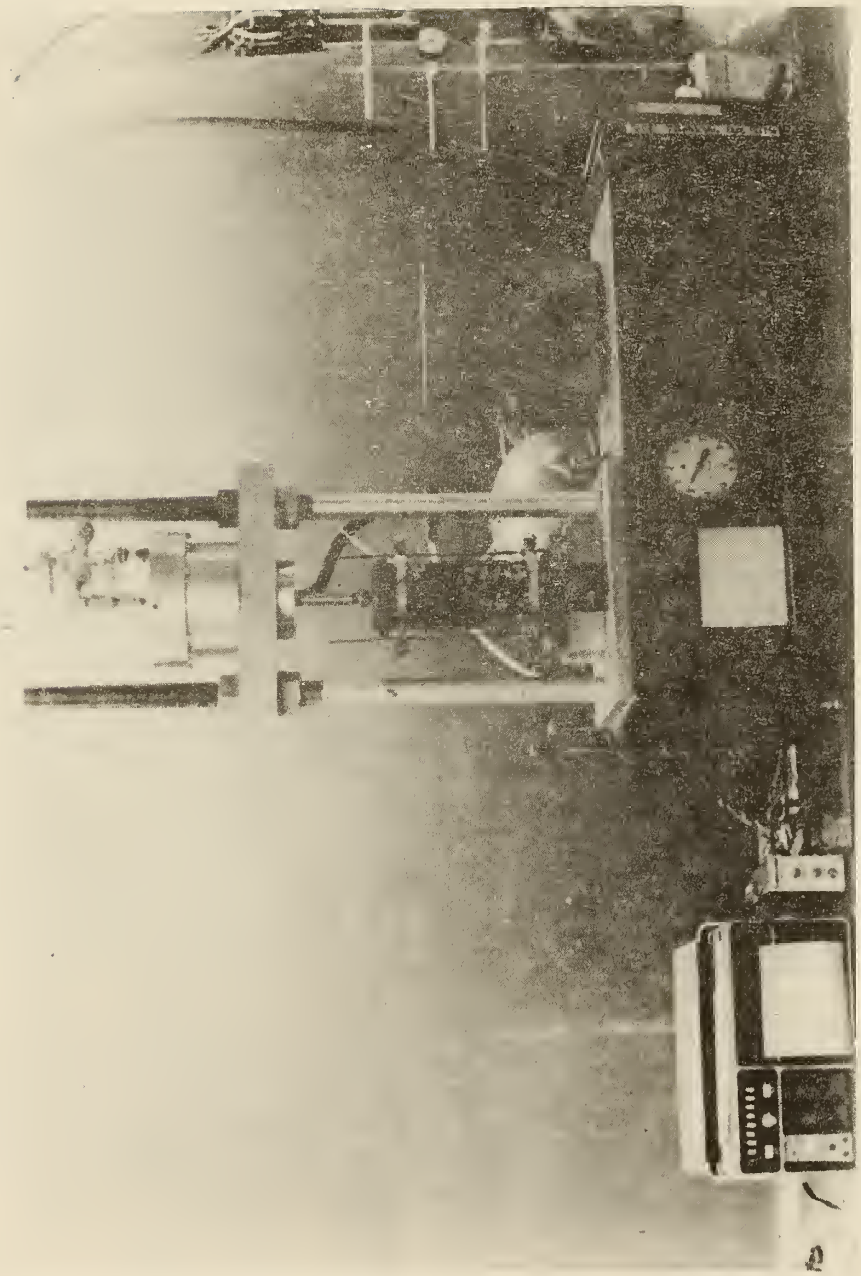


Figure D.1. Photograph of Dynamic Modulus Testing Equipment

The LVDT's or strain gauges should have the capability for operating across the range of strains occurring in the specimen and should, in combination with signal conditioning equipment and the recorder, produce traces on the chart paper that may be easily and accurately measured for the smallest strains (those at a specimen temperature of 40^{o}F (4.4^{o}C) that will be measured). The system should at its highest sensitivity setting display 4 micro strain units or less per mm on the recorded chart for strain gauges. As the LVDT's measure total strain across a gauge length (usually around 4 inches (10.2cm) or more), and a calculation is made to obtain unit strain, sensitivity must be measured in total strain.

As an example, 56 micro inches (.00014cm) of movement will occur over a 4-inch (10.2cm) gauge length in a material having a very high dynamic modulus of 2,500,000 psi (17,250,000kN/m^2) and subjected to 35 psi (241.5kN/m^2) of verticle stress. Assuming .05 inches (12.7mm) is the smallest trace that may be accurately measured, a sensitivity allowing measurement of 4.4 micro inches (.000011176cm) per mm of chart width should be required. A sensitivity of 3 micro inches (.00000762cm) per mm should be sufficient for all practical conditions.

The recorder should have sufficiently rapid response to swing almost full scale in .01 second. Recording oscillographs of good quality using light sensitive paper have proven satisfactorily responsive.

While both LVDT's and bonded strain gauges may be used successfully, more of the material is directly active in the test when measurements are made over a longer gauge length for LVDT's compared to the nominal length for strain gauges. In either case, special attention is warranted to assure firm attachment to the sample. The LVDT clamps should each have four pointed set screws that insure against clamp movement.

3. Load measurement system - load measurements for the varying load used for a haversine pulse produced by the electrohydraulic machine are usually made with a load cell generating a second trace on the chart paper. This may also be used for the two-phase (on-off) load for the square pulse from the pneumatic machine, but is not necessary in this case as it is sufficient to precisely control the air pressure to the air piston. The air pressure is precisely calibrated in terms of load delivered to the sample. Sensitivity in either case must be sufficient to allow accurate calculation of vertical load and thus stress.

4. Temperature control system - One or more temperature chambers having a capacity for 6 specimens may be used to produce temperatures

of 40°F, 70°F, and 100°F (5°, 21° and 38°C) controlled to ± 1°F (.5°C).

5. Loading plate - a hardened, steel plate no less than 1/4 inches (.64cm) thick and with a diameter equal to that of the specimen is required to transfer the load from the testing machine to the specimen.

PREPARATION OF SPECIMENS

1. Laboratory-prepared specimens: Most testing agencies have their own means of preparation and compaction to produce density and stability specimens that serve as the basis for material specifications. Compaction of specimens for dynamic modulus testing should be accomplished by the procedures in use by the agency involved. A specimen suitable for vertical compression testing requires modifications to produce a cylindrical specimen twice as long as its diameter.

One optional procedure is to prepare the bituminous mixture as specified by ASTM Method D 1560, "Test for Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of the Hveem Apparatus." Compaction is them accomplished with a California Kneeding Compactor using steel molding cylinders with 1/4 inch (.64cm) wall thickness, inside diameters of 4 inches (10.2cm) and a height of 10 inches (25.4cm)(twice as high as that recommended by ASTM D1561). A pre-heated insulated feeder trough and a paddle are used as in ASTM D 1561 to introduce the mixture into the mold, but in a different manner. One half of the approximately 4000 grams of bituminous mixture is weighed out and introduced into the trough. A paddle is then used to push 30 approximately equal portions into the mold continuously and uniformly while 30 tamping blows at a pressure of 250 psi (1725kN/m^2) are applied. The second half of the mixture is compacted in the mold in the same manner. This is followed immediately by application of a static load to the specimen while still in the mold. The load is applied with a compression machine by the double plunger method in which metal followers are employed as free-fitting plungers on top and bottom of the specimen. This load is applied at a rate of 0.05 inches (.13cm) per minute until an applied pressure of 1000 psi (6900kN/m^2) is reached. The load is then removed immediately. After the specimen is sufficiently cooled so that it will not deform in the mold, it is removed from the mold and placed on a smooth flat surface to cool to room temperature. The resulting bulk specific gravity is reported to approximate very closely that of specimens prepared as specified by ASTM D 1559, "Test for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus," and by ASTM D 1561, "Preparation of Specimens by means of California Kneeding Compactor."

Whatever the procedure used, the diameter of the specimens should be four or more times the maximum nominal size of aggregate specified. A diameter of 4 inches (10.2cm) is normally used with a length of approximately 8 inches (20.3cm). A minimum of three specimens should normally be tested to suitably account for variability in the materials.

2. Pavement cores - During field sampling obtain cores having a minimum height to diameter ratio of 2 and with diameters not less than two times the maximum nominal size of an aggregate particle. Because of the high variability in dynamic modulus found for pavements in the field, six specimens should normally be tested to characterize a pavement section. The cores should be taken from locations selected to provide a representative sample of the pavement section.

As most highway pavement layers are less than 8 inches (20.3cm) thick, it may be necessary to test cores with a two-inch (5.1cm) diameter or else it may not be possible to use these procedures. For thin pavements, it is possible to obtain a dynamic modulus through dynamic indirect tensile tests on specimens of 4 to 6 inches (10.2 to 15.2cm) in diameter.

TEST PROCEDURES

Capping of Specimens - All specimens should be capped with a sulphur mortar as specified by ASTMC617. The procedures for capping may be the same as those used for Portland cement concrete compression specimens except that a special capping fixture for four-inch (10.2cm) diameter specimens must be used.

Place test specimens in a control temperature cabinet and bring them to the specified test temperature. A dummy specimen with a thermo couple in the center can be used to determine when the desired test temperature is reached or the specimens may remain in the controlled temperature environment overnight to insure even distribution of temperature.

Place specimen with strain gauges for strain measurement directly into the loading apparatus (strain gauges are bonded on the specimen prior to placement in the temperature cabinet). Then connect the strain gauge wires to the measurement system, place the hardened steel disk on top of the specimen and center both under the loading apparatus. Adjust and balance the electronic measuring system as necessary.

For specimens using LVDT's for strain measurement, the clamps and LVDT's are to be placed on the specimen as rapidly as possible before the specimen with the hardened steel disk on top is placed under the loading apparatus. The LVDT's must be zeroed prior to continuing.

Apply the selected pulse as previously described without impact, turning on the recorder about every 50 cycles to obtain a few traces of the strains caused by the load pulse. The resilient strain may be measured on the trace as the distance transverse to the edge of the chart paper between the maximum of the trace and the minimum of the trace just before the next load is applied. This measures the strain recovered. Comparisons of the amounts of strain after each 50 cycles should reveal that the amount of strain has stabilized around 200 cycles of loading. The resilient strain after the magnitudes have stabilized may be used in calculating the dynamic modulus.

The specimen may now be removed from the testing machine and disconnected from the strain measurement equipment, and stored until returned to the temperature cabinet in preparation for testing at a new temperature.

It is important to test in order of increasing temperatures of 40°F, 70°F, and 100°F (4.4°, 21,1° & 37.8°C), as the stiffness will decrease almost an order of magnitude between 40°and 100°F (4.4° to 37.8°C). Testing in this order will allow the least possible amount of permanent strain prior to subsequent testing.

All portions of the procedure should be completed as quickly as possible to minimize the variation in temperature in the sample prior to completion of the test. The testing should be completed on a specimen within two minutes after it is removed from the temperature control cabinet. While this may not be possible when LVDT's are used because it takes that long to place the clamps and LVDT's in position and measure the gauge length and another two minutes to zero them, the test may be conducted rapidly enough to avoid important change in temperature. The clamps and LVDT's can also be placed on the specimen prior to removal from the temperature cabinet. If testing is conducted in a room or a temperature control cabinet meeting the specified temperature control tolerance limits, the requirement for expedited testing may be waived.

In the unlikely event that excessive deformation (greater than 2500 micro units of strain) occurs, the maximum loading stress level may be reduced and testing contained as described above.

Calculations

The measured quantity from dynamic modulus testing is the resilient strain taken after sufficient cycles of loading for it to stabilize. If the square load pulse is used, the resilient strain is modified by multiplication by 0.8 to better represent strains from a wheel load. The vertical stress is generally controlled at 35 psi ($241.5 kN/m^2$) (or 17.5 psi ($120.8 kN/m^2$) if exceptionally high strains occur as previously discussed).

The general equation for calculation is:

$$E^*(T) = \frac{\sigma_o}{\varepsilon_o(T)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (D.1)$$

where:

$E^*(T)$ = Dynamic Modulus for the Asphaltic Mixture at temperature T

$\varepsilon_o(T)$ = Resilient unit strain from dynamic modulus test with the specimen at temperature T.

σ_o = Vertical test stress recommended at 35 psi.

$1 \text{ psi} = 6.9 \text{ kN/m}^2$

Plot the results as indicated in Figure D.2 from the replicate tests. From these plots, a suitable curve may be selected for design or analysis. A mean curve with a rough approximation (dependent on number of replicate tests) of the variation around the mean may be appropriate for most uses.

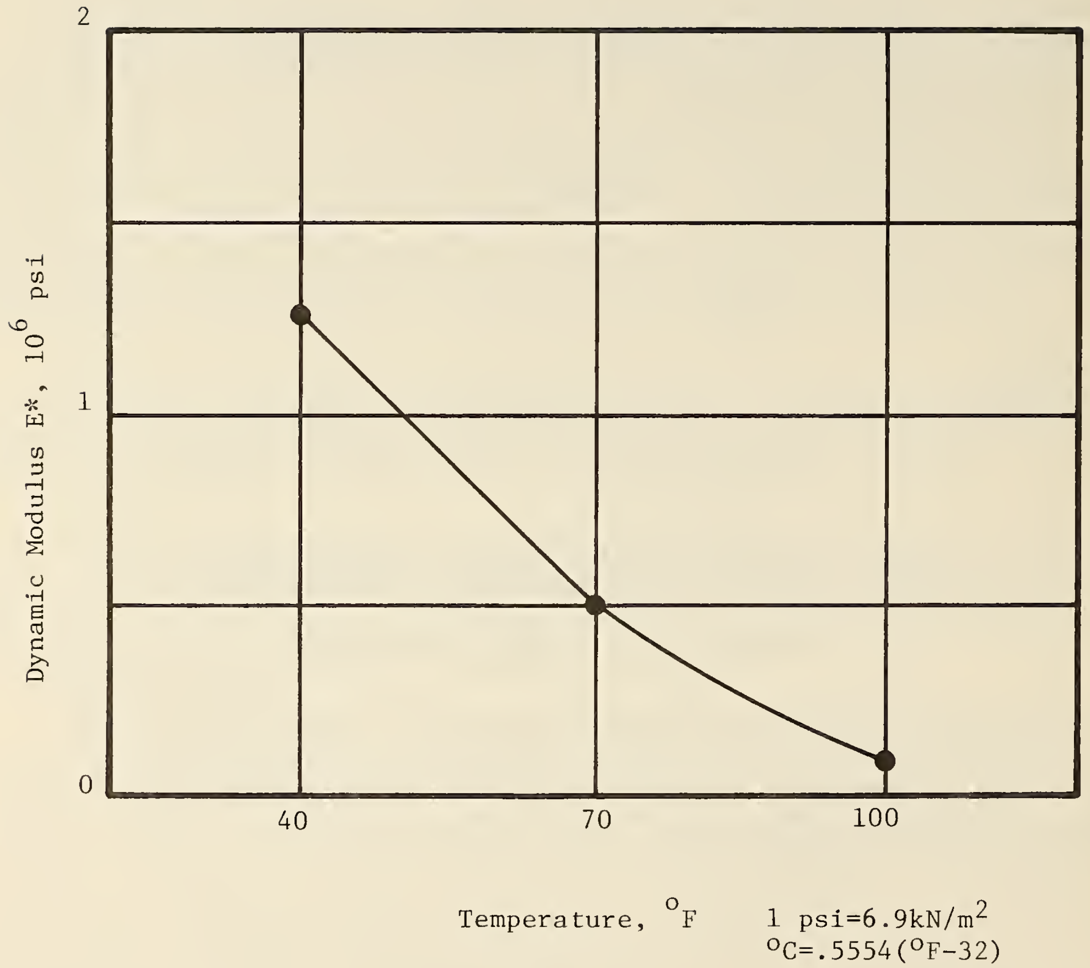


Figure D.2 Typical Dynamic Test Results for an Asphaltic Concrete Specimen Tested at Three Temperatures.

APPENDIX E

RECOMMENDED TEST PROCEDURES -- RESILIENT MODULUS OF ELASTICITY FOR BASE, SUBBASE, AND SUBGRADE MATERIALS

General

The use of elastic layer theory in the prediction of stresses and deflections in pavement systems gives added importance to accurate determination of the modulus of elasticity of base, subbase and subgrade materials. Overwhelming evidence indicates that the modulus of elasticity for most soils is stress sensitive and varies with repeated loading. An adequate laboratory simulation of soil in a base or subgrade then requires application of loads repetitiously to model the intensities and durations of wheel loads.

The triaxial load cell was developed years ago to allow better simulation of a sample of soil in place in the field. The lateral pressure in the cell simulates the resistance of surrounding soil to lateral displacement of the soil sample under vertical load. Equipment capable of applying closely controlled vertical load pulses to represent the intensity and duration of the stresses induced by a passing vehicle was recently introduced. Linear variable differential transformers (LVDTs) are used to produce electronic signals proportional to the amount of movement in the sample. These signals are conditioned for input to a strip recorder, which plots the deformation versus time. The resilient modulus, M_R, is the ratio of stress to resilient strain taken after an appropriate number of cycles of loading and at an appropriate level of vertical stress.

The resilient modulus derived under conditions closely simulating those the sample will experience in the field is used in lieu of a static modulus of elasticity (derived from long-term one-cycle tests) to characterize the material for the particular analytical procedure.

Failure to recognize the effects of repetitive loading on soils will involve overestimation of the modulus of elasticity for clay soils and underestimation for granular soils.

Sample Requirements for Resilient Modulus Testing

Resilient modulus testing may be conducted on undisturbed samples representing natural state in the field, samples compacted to optimum density or samples compacted to some intermediate density. Samples may be delivered to the laboratory as undisturbed samples wrapped to avoid moisture change and packed to protect the structural integrity of the sample or as disturbed samples to be compacted to some density.

As most of the resilient modulus testing done is conducted on samples with a diameter of 2.8 inches (7.1cm), a 3-inch (7.6cm) thin-wall tube should be used for collection of undisturbed samples whenever possible. For cohesive soils, larger tubes may be used and the samples trimmed in the laboratory. Samples with a diameter of 1.4 inches (3.6cm) may be tested but require considerable more effort and the results are not considered to be quite as accurate. If the material to be tested is to be used in a new subbase or subgrade for a pavement system. the density must be furnished or determined. This density should be consistent with the density control planned in the field; i.e., if 95% of modified AASHO compaction is to be specified, the optimum density can be established using modified AASHO compactive energy and compacting the sample to 95% of the amount. If some natural density is desired, it may be specified and the samples can be compacted to that amount. The latter requires trial and error. Moisture contents to simulate the field must also be specified or determined. Samples to be compacted in the laboratory may be sent in disturbed state in bags. Four pounds is sufficient for a single triaxial specimen.

Test Design

The repetitive loading triaxial machine allows considerable flexibility in simulation of anticipated field conditions. Those parameters that may be varied include intensity of deviatior stress, lateral pressure, load period from 1/10th of a second upward, rest period between cycle loads on the specimen, sequence of loading and cycles of loading prior to reading test values.

Deviator stresses as low as 1 psi ($6.9 kN/m^2$) and as high as 64 psi ($441.6 kN/m^2$) may be applied. Lateral pressures as low as 1/2 psi ($3.5 kN/m^2$) are not generally applicable as lateral pressure near the surface of the layer should be based on an estimate of the horizontal stresses induced by the load plus the deadload of the overlaying material.

It has been found that 1000 cycles at a specific loading is sufficient to stabilize the resilient modulus for a material and a particular set of loading conditions. 200 cycles will generally be sufficient for granular materials and is frequently adequate for cohesive soils as well.

Standard Test Procedure

The specimen is placed on the triaxial cell base, a membrane applied, the LVDT's clamped in place so that they measure vertical deformation of the middle third of the specimen and a vacuum is applied within the sample and a vacuum chamber to insure that there is no leakage through the membrane. The triaxial cell is then assembled and placed in the triaxial machine. The sample is conditioned by 1,000 cycles of loading at the lowest deviator stress to be applied and at the lateral pressure specified. Measuring equipment is then zeroed after another 200 cycles of loading at the lowest deviator stress. The cyclic load is applied and increased subsequent to test readings at the specified number of cycles for each load level.

The output of the LVDT's is combined for averaging and fed through a signal conditioner to a strip recorder with very rapid response. The recorded cyclic deformation plus the established deviator stress and sample dimensions provide all the information necessary to calculate the resilient modulus at any load level. A resilient modulus is calculated as follows:

$$M_R = \frac{\sigma_d}{\varepsilon_r} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (E.1)$$

where:

M_R = Resilient Modulus

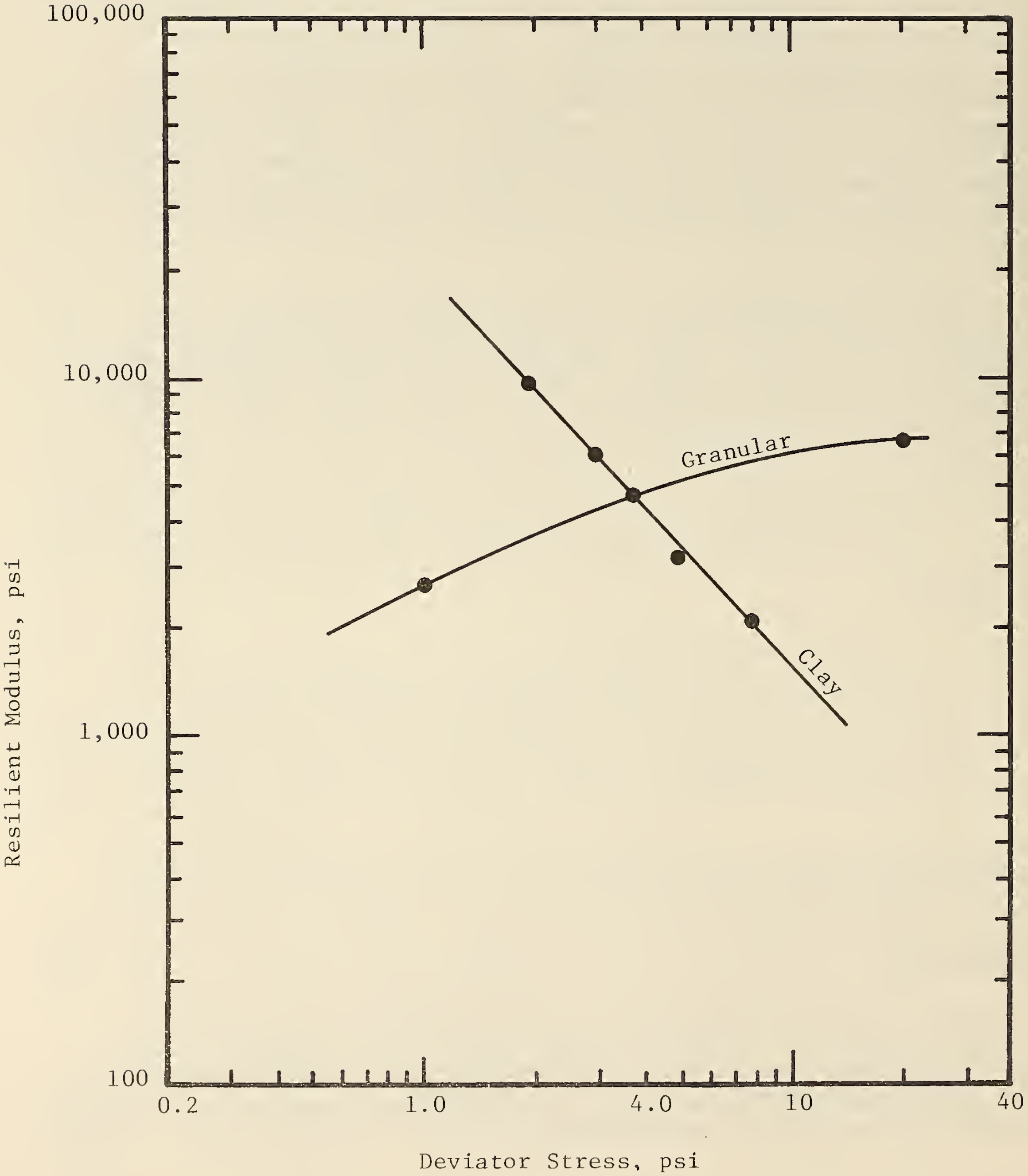
σ_d = Deviator Stress, psi (1 psi=6.9 kN/m^2)

ε_r = Resilient Strain, in./in. (1 in=2.54 cm)

The resilient moduli at the various load levels is then plotted on log-log paper to give clear insight as to the variation in resilient modulus with stress intensity.

Test Results

Test results are summarized in the form of a curve relating resilient modulus to deviator stress level at the specified lateral pressure and loading conditions (See Figure E.1). Additional information and recommendations may also be provided from insight into soil behavior gained during test observations.



1 psi=6.9kN/m^2

Figure E.1 Relation Between Resilient Modulus And Stress for Typical Clay and Granular Soils

APPENDIX F

Random Order Input Guide for RPOD1

RPOD1 - RIGID PAVEMENT OVERLAY DESIGN PROGRAM, VERSION 1.0

THIS PAVEMENT OVERLAY DESIGN COMPUTER PROGRAM WAS DEVELOPED BY AUSTIN RESEARCH ENGINEERS INC (2600 DELLANA LANE, AUSTIN, TEXAS 78746, PHONE (512) 327-3520, TWX 910-874-1324 ARE INC AUS) UNDER FEDERAL HIGHWAY ADMINISTRATION CONTRACT NO. DOT-FH-11-8544 IN AUGUST 1977. DEVELOPEMENT OF THE DESIGN PROCEDURE IS PRESENTED IN FEDERAL HIGHWAY ADMINISTRATION REPORT NO. FHWA-RD-77-66 AND USE OF THE PROCEDURE IS DESCRIBED IN REPORT NO. FHWA-RD-77-67.

THIS PROGRAM REFLECTS THE VIEWS OF AUSTIN RESEARCH ENGINEERS INC AND NOT NECESSARILY THOSE OF THE DEPARTMENT OF TRANSPORTATION. HOWEVER, ANY USER OF THE PROGRAM MUST ASSUME ULTIMATE RESPONSIBILITY FOR ITS RESULTS.

INPUT GUIDE

INSTRUCTIONS TO THE PROGRAM ARE SUPPLIED IN THE FORM OF DIRECTIVES. A DIRECTIVE OCCUPIES EITHER THE FIRST OR SECOND HALF OF A CARD (COLUMNS 1-40 OR 41-80). THE FIRST EIGHT CHARACTERS OF EACH DIRECTIVE CONTAIN A KEYWORD IDENTIFYING THE TYPE OF INFORMATION BEING ENTERED. ALL KEYWORDS MAY BE ABBREVIATED TO THEIR FIRST FOUR CHARACTERS, THE REST OF THE IDENTIFIER IS IGNORED. IF THE FIRST FOUR CHARACTERS OF A DIRECTIVE ARE BLANK, THEN THE WHOLE DIRECTIVE IS SKIPPED, AND READING CONTINUES WITH THE NEXT DIRECTIVE. THIS MEANS THAT ALL DIRECTIVES MAY BEGIN IN COLUMN ONE AT THE OPTION OF THE USER.

MORE THAN ONE PROBLEM MAY BE SOLVED IN A SINGLE EXECUTION OF THE PROGRAM. EACH PROBLEM IS PREFACED WITH A 'PROBLEM' DIRECTIVE AND THE LAST PROBLEM OF A RUN IS TERMINATED BY AN 'END' DIRECTIVE. ALL RELEVANT INFORMATION MUST BE SUPPLIED FOR THE FIRST PROBLEM OF A RUN VIA THE VARIOUS DIRECTIVES WHICH ARE EXPLAINED BELOW. SUBSEQUENT PROBLEMS IN THE SAME RUN NEED ONLY SPECIFY DIRECTIVES WHICH ARE TO BE CHANGED, ALL OTHER VALUES WILL BE RETAINED FROM THE PRECEDING PROBLEM, WITH THE EXCEPTION OF THE CORNER DIRECTIVE, WHICH APPLIES ONLY TO THE CURRENT PROBLEM. ALL DATA ON A SINGLE DIRECTIVE MUST BE SUPPLIED, HOWEVER, EVEN IF ONLY ONE NUMBER IS BEING CHANGED.

ALL DIRECTIVES SHARE A COMMON FORMAT, BUT THE MEANINGS OF THE FIELDS DIFFER DEPENDING ON THE KEYWORD IDENTIFIER. THESE SPECIFIC MEANINGS ARE DESCRIBED BELOW UNDER THE HEADINGS OF THE APPROPRIATE KEYWORDS. THE GENERAL FORMAT IS AS FOLLOWS:

FIELD NAME	COLUMN NUMBERS	TYPE OF VALUE	FORMAT USED
KEYWORD	1-8	CHARACTER	2A4
IVL	9-10	INTEGER	I2
VAL(1)	11-20	REAL	F10.0
VAL(2)	21-25	REAL	F5.0
VAL(3)	26-30	REAL	F5.0
ITYPE(1)	31-34	CHARACTER	A4
ITYPE(2)	35-38	CHARACTER	A4

ADDING 40 TO THE COLUMNS LISTED ABOVE GIVES THE CORRESPONDING COLUMN NUMBER FOR A DIRECTIVE WHICH IS PUNCHED IN THE SECOND HALF OF THE CARD.

SOME DIRECTIVES REQUIRE FURTHER VALUES FROM CARDS WHICH ARE PLACED IMMEDIATELY AFTER THE CARD ON WHICH THE DIRECTIVE APPEARS. THESE CARDS WILL BE READ IN 8F10.0 FORMAT. AS MANY CARDS AS ARE NEEDED TO HOLD THE NUMBER OF VALUES TO BE INPUT SHOULD BE SUPPLIED. IF TWO SUCH DIRECTIVES ARE PUNCHED ON A SINGLE CARD, THE EXTRA CARDS FOR THE DIRECTIVE IN COLUMNS 1 THROUGH 40 SHOULD PRECEDE THOSE REQUIRED FOR THE ONE IN COLUMNS 41 THROUGH 80.

KEYWORD DICTIONARY

BOND BKR

THIS DIRECTIVE IS NEVER REQUIRED. IF IT DOES NOT APPEAR, THEN THE DEFAULT VALUES FOR THE BOND BREAKER LAYER WILL BE USED. DEFAULT VALUES WILL ALSO BE SUPPLIED FOR ANY FIELD ON THE DIRECTIVE WHICH IS LEFT BLANK.

NOTE THAT A BOND BREAKER LAYER IS ONLY USED IF THE 'UNBD' OPTION IS SELECTED ON THE OVERLAY DIRECTIVE, INDICATING THAT AN UNBONDED OVERLAY IS TO BE BUILT (SEE COMMENTS FOR OVERLAY DIRECTIVE BELOW). IF THIS OPTION IS NOT SPECIFIED, THEN THE BOND BREAKER DESCRIPTION WILL BE IGNORED, ALTHOUGH THE VALUES SUPPLIED WILL STILL BE AVAILABLE TO SUBSEQUENT PROBLEMS.

FIELD DEFINITIONS:

VAL(1) = MODULUS OF BOND BREAKER LAYER IN PSI.
(DEFAULT IS 100000.0)
VAL(2) = THICKNESS OF BOND BREAKER LAYER IN INCHES.
(DEFAULT IS 1.0)
VAL(3) = POISSON/S RATIO FOR BOND BREAKER LAYER
(DEFAULT IS 0.3)

CORNER

THIS DIRECTIVE IS NEVER REQUIRED. IT IS USED ONLY WITH JCP EXISTING PAVEMENT, AND PROVIDES A MEASURED RATIO OF CORNER DEFLECTION TO INTERIOR DEFLECTION FOR A GIVEN PAVEMENT SECTION. THIS RATIO IS USED TO OBTAIN THE LOAD LOCATION (STRESS ADJUSTMENT) FACTOR FOR THE DETERMINATION OF REMAINING LIFE AND, FOR JCP OVERLAYS, OF ESTIMATED OVERLAY LIFE. THE LOAD LOCATION FACTOR IS DETERMINED USING INTERPOLATION IN A CURVE OF STRESS RATIO VS. DEFLECTION RATIO. THIS DIRECTIVE APPLIES ONLY TO THE PROBLEM WITH WHICH IT WAS READ. DEFAULT VALUE OF THE LOAD LOCATION FACTOR FOR JCP EXISTING PAVEMENT AND JCP/JCP OVERLAYS IS 1.5.

FIELD DEFINITIONS:

VAL(1) = RATIO OF DEFLECTION MEASURED AT A CORNER (JCP) TO THAT MEASURED AT AN INTERIOR POINT.

DEFLECT

THIS DIRECTIVE IS REQUIRED FOR THE FIRST PROBLEM OF EVERY RUN. DEFAULT VALUES WILL NOT BE SUPPLIED BY THE PROGRAM. NOTE THAT THE COORDINATE SYSTEM USED HERE IS THE SAME AS THAT USED FOR THE LOADS DIRECTIVE. IT WILL GENERALLY SAVE KEY-PUNCHING ON MULTI-PROBLEM RUNS IF THE DEFLECTION MEASUREMENTS ARE TAKEN AT THE ORIGIN.

IF THE DESIGN DEFLECTION ON THIS DIRECTIVE AND DEFLECTION LOAD AND THE DEFLECTION PRESSURE ON THE LOADS DIRECTIVE ARE ALL ZERO, THE VALUE OF MODULUS READ ON THE SUBGRADE LAYER DIRECTIVE WILL BE USED FOR REMAINING LIFE AND OVERLAY CALCULATIONS.

FIELD DEFINITIONS:

VAL(1) = DESIGN DEFLECTION IN INCHES. THIS DEFLECTION SHOULD BE REPRESENTATIVE OF THE MORE DISTRESSED PORTIONS OF THE PAVEMENT, HENCE A MINIMUM CONFIDENCE LEVEL OF 90 PERCENT IS RECOMMENDED. (NO DEFAULT VALUE)

VAL(2) = X-COORDINATE OF DEFLECTION MEASUREMENT IN INCHES. (NO DEFAULT VALUE)

VAL(3) = Y-COORDINATE OF DEFLECTION MEASUREMENT IN INCHES. (NO DEFAULT VALUE)

END

THIS DIRECTIVE INFORMS THE PROGRAM THAT NO MORE PROBLEMS ARE TO BE EXECUTED IN THIS RUN. EVERY INPUT DECK MUST CONTAIN AN END DIRECTIVE, EVEN IF ONLY ONE PROBLEM IS TO BE ANALYZED. THIS DIRECTIVE HAS NO PARAMETERS.

LAB DATA

THIS DIRECTIVE IS REQUIRED IF THE LOAD UNDER WHICH THE DEFLECTION MEASUREMENTS WERE TAKEN DIFFERS SIGNIFICANTLY FROM 18 KIPS (THE DESIGN LOAD). LAB TESTS MUST BE MADE TO DETERMINE ELASTIC MODULUS AS A FUNCTION OF DEVIATOR STRESS FOR THE SUBGRADE MATERIALS. THESE DATA ARE ENTERED ON CARDS WHICH ARE PLACED IMMEDIATELY AFTER THE DIRECTIVE IN 8F10.0 FORMAT. CORRESPONDING VALUES OF MODULUS AND DEVIATOR STRESS ARE ENTERED IN PAIRS, WITH THE MODULUS VALUE FIRST. A MINIMUM OF TWO POINTS AND A MAXIMUM OF 10 MAY BE SUPPLIED. FOUR POINTS CAN BE PUNCHED ON A SINGLE CARD. NO FIELDS CAN BE SKIPPED, AS MANY CARDS AS ARE NECESSARY TO HOLD THE DATA MUST BE PROVIDED.

FIELD DEFINITIONS:

IVL = NUMBER OF PAIRS OF POINTS TO BE READ. (1 < IVL < 10)
(NO DEFAULT VALUE)

LAYER

THIS DIRECTIVE DEFINES THE PROPERTIES OF A SINGLE LAYER OF THE EXISTING PAVEMENT. A LAYER DIRECTIVE IS REQUIRED FOR EACH LAYER DOWN TO AND INCLUDING THE SUBGRADE. AFTER THE FIRST PROBLEM IT IS POSSIBLE TO CHANGE THE VALUES FOR A SINGLE LAYER WITHOUT ALTERING THE OTHERS BY INCLUDING A LAYER DIRECTIVE FOR THAT LAYER ONLY. A MAXIMUM OF FOUR LAYERS ARE PERMITTED, UNLESS A BOND BREAKER LAYER IS TO BE USED (SEE OVERLAY DIRECTIVE) IN WHICH CASE ONLY THREE EXISTING LAYERS ARE ALLOWED. IF THE THICKNESS OF THE SUBGRADE LAYER IS INPUT AS ZERO, THEN IT IS ASSUMED TO BE SEMI-INFINITE. OTHERWISE THE PROGRAM WILL SIMULATE THE PRESENCE OF BEDROCK AT THE INDICATED DEPTH BELOW THE TOP OF THE SUBGRADE WHEN PERFORMING DEFLECTION CALCULATIONS.

FIELD DEFINITIONS:

IVL = LAYER NUMBER. LAYERS ARE NUMBERED FROM THE TOP DOWN.
0 < IVL < 5
(NO DEFAULT VALUE)
VAL(1) = MODULUS OF ELASTICITY FOR LAYER MATERIAL IN PSI.
(NO DEFAULT VALUE)
VAL(2) = LAYER THICKNESS IN INCHES (ZERO IF INFINITE).
(NO DEFAULT VALUE UNLESS SUBGRADE)
VAL(3) = POISSON/S RATIO FOR LAYER MATERIAL.
(DEFAULT VALUE BASED ON MATERIAL TYPE)
ITYPE(1) = MATERIAL TYPE AS FOLLOWS:
'AC ' - ASPHALTIC CONCRETE,
'CRCP' - CONTINUOUSLY REINFORCED CONCRETE PAVEMENT,
'GRAN' - GRANULAR BASE MATERIAL,
'JCP ' - JOINTED CONCRETE PAVEMENT,
'STAB' - STABALIZED BASE MATERIAL,
'SUBG' - SUBGRADE LAYER.
(MUST BE JCP OR CRCP IF TOP LAYER)

ITYPE(2) = RIGID BASE INTERFACE TYPE (REQUIRED IF RIGID BASE REQUESTED):
'FF ' - FULL FRICTION INTERFACE,
'NF ' - NO FRICTION INTERFACE.
(NO DEFAULT VALUE)

LOADS

THIS DIRECTIVE DESCRIBES THE LOAD GEOMETRY OF THE DEFLECTION MEASURING DEVICE. IT IS REQUIRED FOR THE FIRST PROBLEM OF A RUN, BUT ORDINARILY NEED NOT BE INPUT AGAIN UNLESS MORE THAN ONE SUCH DEVICE IS EMPLOYED. FROM ONE TO FOUR UNIFORM CIRCULAR

LOADS MAY BE MODELLED WITH THIS DIRECTIVE. A SINGLE LOAD FORCE AND PRESSURE ARE INPUT FOR ALL OF THESE LOADS. AN EXTRA CARD MUST BE PROVIDED IMMEDIATELY AFTER THIS DIRECTIVE, SPECIFYING THE POSITIONS OF THE LOADS AS PAIRS OF X AND Y COORDINATES IN 8F10.0 FORMAT. THESE ARE THE HORIZONTAL CARTESIAN COORDINATES IT WILL USUALLY BE FOUND CONVENIENT TO SELECT A COORDINATE SYSTEM WHICH PLACES THE POINT AT WHICH DEFLECTIONS ARE MEASURED AT THE ORIGIN (SEE DEFLECT DIRECTIVE ABOVE).

FIELD DEFINITIONS:

IVL = NUMBER OF LOADS (0 < IVL < 5).
(NO DEFAULT VALUE)
VAL(1) = DEFLECTION LOAD FORCE IN POUNDS.
(NO DEFAULT VALUE)
VAL(2) = DEFLECTION LOAD PRESSURE IN PSI.
(NO DEFAULT VALUE)

OVERLAY

THIS DIRECTIVE DEFINES THE TYPE OF OVERLAY TO BE BUILT. WITH IT THE DESIGNER SPECIFIES THE MATERIAL TO BE USED, ITS PROPERTIES, AND THE PRESENCE OR ABSENCE OF A BOND BREAKER LAYER. IT IS IMPORTANT TO NOTE THAT THE INCLUSION OF A BOND BREAKER LAYER (VIA THE 'UNBD' OPTION) REDUCES THE MAXIMUM NUMBER OF EXISTING PAVEMENT LAYERS FROM FOUR TO THREE. AN OVERLAY DIRECTIVE IS REQUIRED FOR THE FIRST PROBLEM OF EVERY RUN.

FIELD DEFINITIONS:

VAL(1) = MODULUS OF OVERLAY MATERIAL IN PSI.
(NO DEFAULT VALUE)
VAL(2) = POISSON/S RATIO FOR OVERLAY MATERIAL.
(DEFAULT VALUE BASED ON MATERIAL TYPE)
ITYPE(1) = MATERIAL TYPE AS FOLLOWS:
'AC' = ASPHALTIC CONCRETE OVERLAY,
'CRCP' = CONTINUOUSLY REINFORCED CONCRETE PAVEMENT,
'JCP' = JOINTED CONCRETE PAVEMENT.
ITYPE(2) = BOND BREAKER CONDITION AS FOLLOWS:
= BLANK IF AC OVERLAY,
= 'BOND' IF BONDED PORTLAND CEMENT OVERLAY,
= 'UNBD' IF UNBONDED PCC OVERLAY.
(BOND BREAKER LAYER WILL BE USED)

PAVEMENT

THIS DIRECTIVE DESCRIBES THE CONDITION OF THE EXISTING PAVEMENT. IT IS REQUIRED FOR THE FIRST PROBLEM OF EVERY RUN. NOTE THAT LAYER DIRECTIVES ARE ALSO REQUIRED FOR EACH LAYER INCLUDING THE TOP ONE.

FIELD DEFINITIONS:

IVL = NUMBER OF LAYERS IN EXISTING PAVEMENT DOWN TO AND INCLUDING THE SUBGRADE. AT LEAST ONE AND NOT MORE THAN FOUR LAYERS MAY BE SPECIFIED (THREE IF BOND BREAKER LAYER SPECIFIED ON OVERLAY DIRECTIVE). (NO DEFAULT VALUE)

VAL(1) = NUMBER OF 18 KIP EQUIVALENT SINGLE AXLE WHEEL LOADS APPLIED TO DATE (PUNCHED WITH DECIMAL POINT). (DEFAULT IS 1.)

VAL(2) = CONCRETE FLEXURAL STRENGTH IN PSI. (DEFAULT IS 690.0)

ITYPE = 8-CHARACTER FIELD SPECIFYING PAVEMENT CONDITION:
- BLANK - NO CRACKING OR VOIDS PRESENT.
- 'VOID ' - VOIDS PRESENT BUT NO CRACKING.
- 'TYPE 1,2' - TYPE 1 OR 2 CRACKING PRESENT.
- 'VOID 1,2' - TYPE 1 OR 2 CRACKING WITH VOIDS PRESENT.
- 'TYPE 3,4' - TYPE 3 OR 4 CRACKING PRESENT.
- 'MECH BKN' - PAVEMENT WILL BE MECHANICALLY BROKEN PRIOR TO OVERLAY.

PROBLEM

THIS DIRECTIVE SIGNALS THE BEGINNING IF A GROUP OF DIRECTIVES THAT DESCRIBE A SINGLE PROBLEM FOR WHICH SOLUTIONS OF ALLOWABLE TRAFFIC AS A FUNCTION OF OVERLAY THICKNESS ARE DESIRED. IT PERMITS THE USER TO SPECIFY A TITLE AND A PROBLEM NUMBER WHICH WILL APPEAR IN THE PRINTED OUTPUT AND CAN BE USED TO IDENTIFY THE RESULTS. IF A NON-ZERO DIGIT APPEARS ANYWHERE BETWEEN COLUMNS 11 AND 20 OF THIS DIRECTIVE, THEN AN 80-CHARACTER TITLE IS READ FROM AN EXTRA CARD WHICH IMMEDIATELY FOLLOWS THE PROBLEM DIRECTIVE. THIS TITLE WILL REMAIN IN EFFECT UNTIL ANOTHER IS PROVIDED.

FIELD DEFINITIONS:

IVL = PROBLEM NUMBER (IVL < 100). (DEFAULT IS 1 IF FIRST PROBLEM, PREVIOUS PROBLEM NUMBER PLUS ONE OTHERWISE)

VAL(1) = 0 IF NO TITLE CARD,
> 0 IF TITLE CARD FOLLOWS.

TRAFFIC

THIS DIRECTIVE IS NEVER REQUIRED. IT PROVIDES UP TO 5 DESIGN TRAFFIC VALUES, FOR WHICH OVERLAY THICKNESSES ARE OBTAINED BY INTERPOLATION IN THICKNESS AS A FUNCTION OF LOG(PREDICTED APPLICATIONS TO FAILURE). CONSERVATIVE OVERLAY THICKNESSES ARE CALCULATED IF THE SPECIFIED FATIGUE LIFE IS LESS THAN THAT FOR THE RECOMMENDED MINIMUM OVERLAY THICKNESS.

AN EXTRA CARD MUST BE PROVIDED IMMEDIATELY AFTER THIS DIRECTIVE, SPECIFYING THE DESIGN TRAFFIC VALUES IN 5F10.0 FORMAT.

FIELD DEFINITIONS:

IVL = NUMBER OF DESIGN TRAFFIC VALUES (LESS THAN OR EQUAL TO 5)
(DEFAULT: 0)

APPENDIX G

FIXED-ORDER INPUT GUIDE FOR RPOD1

The fixed-order input guide in Table G-1 is provided for beginning users of RPOD1 who may find the flexibility provided by the previous input guide (Appendix F) somewhat confusing at first. It consists of a pictorial representation of the input cards and the fields on each, with a number for each card type; each type is then listed by number and explained. The figure also provides a quick check against a listing of the data to be run. Not all of the card types will normally be present for one problem. It should be noted that the names on the fields shown on the figure are for reference in the descriptive text following and are not in general the variable names used in the program.

It is recommended that a beginning user read through Appendix F for general information on the structure of the data input and on stacking decks for multiple problem runs, even if he intends to use this fixed-order input guide.

TABLE G.1

FIXED-ORDER INPUT GUIDE FOR RPOD1

CARD TYPE	1 8	10	20	25	30	34	38	40	50	60	70	80
1	PROBLEM	PN	TCSW									
2	TITLE CARD (REQUIRED ONLY IF TCSW > 0.)											
3	PAVEMENT	NL	NESAWL	FC	☒	EPCON						
4	LAYER	N	EN	THN	VN	MTN						
5	LOADS	L	FORS	PRES								
6	XL1		YL1	XL2		YL2			XL3	YL3	XL4	YL4
7	DEFLECT	☒	DESDEF	XDEF	YDEF							
8	LAB DATA	ND										
9	E1		DS1	E2		DS2			E3	DS3	E4	DS4
10	OVERLAY	☒	EOV	VOV	☒	OVTYP	BCON					
11	BOND BKR	☒	EBB	THBB	VBB							
12	CORNER	☒	CTIRAT									
13	TRAFFIC	NT										
14	TRAF1		TRAF2	TRAF3		TRAF4			TRAF5			
15	END											

Card Type 1: New Problem Card

This card is used to designate the start of a new problem where:

PN = Problem number (Col. 9-10, integer).

TCSW = Title card switch (Col. 11-20, real). If this value is greater than zero, the entire 80 columns of the following card will be read as a title card.

Card Type 2: Title Card

This card is required only if the value of TCSW on the "New Problem Card" is greater than zero. (Col. 1-80, alphanumeric). This card must not be present if TCSW is equal to zero.

Card Type 3: Existing Pavement Card

This card describes the condition of the existing pavement where:

NL = Number of layers in existing pavement structure, down to and including the subgrade (Col. 9-10, integer). At least one and not more than four layers may be specified (only three if the new pavement structure is to include a bond breaker). This value also designates the number of Card Type 4 (layer Cards) to be expected.

NESAWL = Number of 18 kip equivalent single axle wheel loads applied to date (Col. 11-20, real, must be non-zero, therefore default value = 1).

FC = Concrete flexural strength, psi (Col. 21-25, real, default value = 690.0 psi).

EPCON = Existing pavement condition (Col. 31-38, alphanumeric).

Blank	- No cracking or voids present.
"VOID"	- Voids present, but no cracking.
"TYPE 1,2"	- Type 1 or 2 cracking present.
"VOID 1,2"	- Type 1 or 2 cracking with voids present.
"TYPE 3,4"	- Type 3 or 4 cracking present.
"MECH BKN"	- Pavement will be mechanically broken prior to overlay.

Card Type 4: Layer Card

This card type defines the properties of a single layer of the existing pavement and is required for each layer, down to and including the subgrade. The layers are numbered from the top down and a maximum of 4 layers is permitted unless a bond breaker is specified for the overlay in which case only 3 layers are permitted. If the thickness of the subgrade is input as zero, the program will assume it to be infinite. If the input subgrade thickness is non-zero, the program will assume the presence of bedrock beneath the subgrade layer when performing deflection calculations. The variable definitions are:

N = Layer number (Col. 9-10, integer, right justify).
EN = Elastic modulus of layer N, psi (Col. 11-20, real).
THN = Thickness of layer N, inches (Col. 21-25, real).
VN = Poisson's ratio for layer N (Col. 26-30, real).
MTN = Material type of layer N (Col. 31-34, alphanumeric)
"AC" - Asphaltic concrete,
"CRCP" - Continuously reinforced concrete pavement,
"GRAN" - Granular base material,
"JCP" - Jointed concrete pavement,
"STAB" - Stabilized base material,
"SUBG" - Subgrade layer.
(Top layer must be either JCP or CRCP)

Card Types 5 and 6: Load Cards

These cards describe the load magnitude (Card Type 5) and geometry (Card Type 6) of the deflection measuring device. From one to four uniform circular loads (of equal magnitude) may be specified (Card Type 5) where:

L = Number of loads (Col. 9-10, integer, right justify).
FORS = Load magnitude, pounds (Col. 11-20, real).
PRES = Load pressure, psi (Col. 21-25, real).

Now, in order to describe the load geometry (Card Type 6), it is necessary to select a cartesian coordinate system with the XL_i and YL_i values on the card representing the x and y coordinates of each load (each value in consecutive 10 column fields, real).

Card Type 7: Design Deflection Card

This card designates the magnitude of the design deflection and also its location in the selected cartesian coordinate system.

DESDEF = Design deflection, inches (Col. 11-20, real). This value should be representative of the more distressed portions of the pavement, hence a minimum confidence level of 90 percent is recommended.
XDEF = x - coordinate of the design deflection location (Col. 21-25, real).
YDEF = y - coordinate of the design deflection location (Col. 26-30, real).

Note: Should the values of the design deflection, deflection load and deflection pressure all be zero, the value of the subgrade modulus (read from the appropriate type 4 Card) will be used for the remaining life overlay calculations.

Card Types 8 and 9: Lab Data Cards

These cards are required if the load under which the deflection measurements are taken differs significantly from an 18 kip axle (the design load). Lab tests must be made to determine elastic modulus as a function of deviator stress for the subgrade.

Card Type 8 designates that this option has been specified where:

ND = Number of pairs of lab data points (elastic modulus vs. corresponding deviator stress, Col. 9-10, integer, right justify). A minimum of two points and a maximum of 10 may be specified.

Card Type 9 is used to designate the value of elastic modulus vs. deviator stress for each lab data point (read in consecutive 10 column fields, real, four pairs of values per card) where:

E_i = Elastic modulus at point, psi.
DS_i = Deviator stress at point, psi.

Card Type 10: Overlay Card

This card defines the type of overlay to be used. With it, the designer specifies the material type and properties of the overlay and also the presence or absence of a bond breaker layer, where:

EOV = Modulus of overlay, psi (Col. 11-20, real).

VOV = Poisson's ratio of overlay (Col. 21-25, real, default value based on material type).

OVTYP = Material type as follows:
- "AC" - Asphaltic concrete overlay.
- "CRCP" - Continuously reinforced concrete pavement.
- "JCP" - Jointed concrete pavement.

BCON = Bond breaker condition as follows:
- Blank - AC overlay
- "BOND" - Bonded PCC overlay.
- "UNBD" - Unbonded PCC overlay (bond breaker will be used, reduces maximum allowable number of layers in existing pavement from four to three).

Card Type 11: Bond Breaker Card

This card is required only if the overlay is to be unbonded (i.e., BCON = "UNBD" is specified) and if the default values for the bond breaker (see below) are inappropriate.

EBB = Modulus of bond breaker, psi (Col. 11-20, real, default value = 100,000. psi)

THBB = Thickness of bond breaker, inches (Col. 21-25, real, default value = 1.0 inch)

VBB = Poisson's ratio for bond breaker (Col. 26-30, real, default value = 0.3)

Card Type 12: Corner to Interior Stress Ratio Card

This card is not required. It is used only with JCP existing pavement, and provides a measured ratio of corner deflection to interior deflection for a given pavement section. This ratio is used to obtain the load location (stress adjustment) factor for the determination of remaining life and, for JCP overlays, of estimated overlay life. The load location factor is determined using interpolation in a curve of stress ratio versus deflection ratio. The default value of the load location factor for JCP existing pavement and JCP overlays on JCP existing pavements is 1.5.

CTIRAT = Ratio of the deflection measured at a corner (of JCP existing pavement) to that measured at an interior point (Col. 11-20, real).

Card Types 13 and 14: Traffic Cards

These cards are not required unless the user wishes to determine the overlay thicknesses required for some specified design traffic values. To predice these thicknesses, interpolation is performed in a curve of overlay thickness versus the logarithm of predicted pavement life after overlay.

Card Type 13 designates the number of design traffic values to be read and used for interpolation (maximum of 5):

NT = Number of design traffic values (Col. 9-10, integer, right justify).

Card Type 14 designates the magnitudes of these design traffic values, $TRAF_i$ (in consecutive 10 column fields, real).

Card Type 15: End Card

This card informs the program that no more problems are to be executed in this run. Every input deck must contain one at the end of the data, even if only one problem is to be analyzed.

APPENDIX H

Table H.1: Input Guide for RFLCR1

CARD NO.	1	11	21	31	41	51	61	71 80
1		PAVEMENT LOCATION CARD						
2		PAVEMENT LOCATION CARD						
3	PVTYPE JC ☒	EC	ALFC	THC	DENSC	SPACE	DS	
4	STEEL	ES	ALFS	AS	SSIG	SMU		
5	HORZ CHAR	TH	WH	TL	WL	T1		
6	VERT CHAR	WJTALT	FLTRAN					
7	OVTYPE ☒	EOV	ALFV	THOV	DENSOV	OVMU	EDV	OVBS
8	OVRTYP	ER	ALFR	AR	EPSR			
9	BOND BREAK	BBW						
10	INTER LAYR	E2	ALF2	TH2	DENS2	EPS2	ED2	
11	DESIGN	DTC	DT2	DTV	DLOAD	WLOAD		
12	SLOPE SWCH	SLPSW						
13	APS							

1	EOV	EDV	THOV	BBW	DTC	DT2	DTV	SLPSW
2	APS							

Data Long Form: (required for first problem of every run)

Cards 1 & 2 - Pavement Description and Location Cards (Col. 1-80, alphanumeric)

Card 3 - Existing Pavement Properties:

PVTYPE = Existing type of pavement (JRCP, JCP, CRCP, etc.) (Col. 1-4, alphanumeric, right justify).
UC = Designation for cracked or uncracked-jointed pavement (Col. 5, alphanumeric); UC = "U", uncracked or jointed pavement, otherwise cracked pavement is assumed.
EC = Elastic modulus, psi (Col. 11-20, real).
ALFC = Thermal Coefficient, in./in./°F (Col. 21-30, real).
THC = Thickness, inches (Col. 31-40, real).
DENSC = Density, pcf (Col. 41-50, real).
SPACE = Joint or crack spacing, feet (Col. 51-60, real).
DS = Movement at sliding, inches (Col. 61-70, real).

Card 4 - Existing Pavement Reinforcement Properties: (Leave this card blank if pavement is not reinforced.)

ES = Elastic modulus of steel, psi (Col. 11-20, real, default value = 29,000,000 psi).
ALFS = Steel thermal coefficient, in./in./°F (Col. 21-30, real).
AS = Area of steel per foot width, in.^{2} (Col. 31-40, real).
SSIG = Perimeter of steel, inches (Col. 41-50, real).
SMU = Steel to concrete bonding stress, psi (Col. 51-60, real).

Card 5 - Horizontal Characterization of Pavement:

TH = Mean high temperature, °F (Col. 11-20, real).
WH = Joint width at temperature T_H , inches (Col. 21-30, real).
TL = Mean low temperature, °F (Col. 31-40, real).

WL = Joint width at temperature T_L , inches (Col. 41-50, real).
T1 = Minimum temperature observed since construction of pavement, °F (Col. 51-60, real).

Card 6 - Vertical Characterization of Pavement:

WJTALT = Mean joint width (Table 2.5), inches (Col. 11-20, real).
FLTRAN = Load transfer from cumulative frequency diagram, percent/100 (Col. 21-30,real).

Card 7 - Overlay Properties:

OVTYPE = Overlay type (Col. 1-4, alphanumeric, right justify).
EOV = Creep modulus, psi (Col. 11-20, real).
ALFV = Thermal coefficient, in./in./°F (Col. 21-30, real
THOV = Thickness, inches (Col. 31-40, real).
DENSOV = Density, pcf (Col. 41-50, real).
OVMU = Poisson's ratio (Col. 51-60, real).
EDV = Dynamic modulus, psi (Col. 61-70, real).
OVBS = Overlay to existing surface bonding stress, psi (Col. 71-80, real).

Card 8 - Overlay Reinforcement Properties: (Leave this card blank if overlay is non-reinforced.)

OVRTYP = Overlay reinforcement type (Col. 1-10, alphanumeric, right justify)
ER = Elastic modulus, psi (Col. 11-20, real).
ALFR = Thermal coefficient, in./in./°F (Col. 21-30, real).
AR = Area of reinforcement per foot width, in.^{2} (Col. 31-40, real).
EPSR = Allowable tensile strain, in./in. (Col. 41-50, real).

Card 9 - Bond Breaker: (Leave this card blank if no bond breaker.)

BBW = Width or length in direction of traffic, feet (Col. 11-20, real).

Card 10 - Intermediate Layer Properties: (Leave this card blank if no intermediate layer.)

E2 = Creep modulus, psi (Col. 11-20, real).
ALF2 = Thermal coefficient, in./in./°F (Col. 21-30, real).
TH2 = Thickness, inches (Col. 31-40, real).
DENS2 = Density, pcf (Col. 41-50, real).
EPS2 = Allowable strain, in./in. (Col. 51-60, real).
ED2 = Dynamic modulus, psi (Col. 61-70, real).

Card 11 - Design Temperature Changes, Design Load

DTC = Design temperature change for existing pavement, °F (Col. 11-20, real).
DT2 = Design temperature change for intermediate layer, °F (Col. 21-30, real).
DTV = Design temperature change for the overlay, °F (Col. 31-40, real).
DLOAD = Design load weight, pounds (Col. 41-50, real).
WLOAD = Width of design load, inches (Col. 51-60, real).

Card 12 - Friction Curve Switch:

SLPSW = Switch to designate whether slope of friction curve is to be multiplied by ratio of original overburden weight to new overburden weight; if SLPSW > 0.0, slope will be multiplied by this ratio (Col. 11-20, real).

Card 13 - New Problem Switch

APS = Switch to designate type of data following or terminate run (Col. 1-4, alphanumeric, left justify)
= "ALL" - Read new data using long form.
= "PART" - Read new data using short form.
= "STOP" - Terminate run.

Data Short Form: (applicable to successive problems where only changes in the following inputs are necessary)

EOV = Overlay creep modulus, psi (Col. 1-10, real)
EDV = Overlay dynamic modulus, psi (Col. 11-20, real)
THOV = Overlay thickness, inches (Col. 21-30, real)
BBW = Bond breaker width, feet (Col. 31-40, real)
DTC = Design temperature change for existing pavement, °F (Col. 41-50, real)
DT2 = Design temperature change for intermediate layer, °F (Col. 51-60, real)
DTV = Design temperature change for overlay, °F (Col. 61-70, real)
SLPSW = Slope switch
= 0 use same friction curve after overlay as before overlay
> 0 use friction curve before overlay multiplied by ratio of new to old overburdens for friction curve after overlay (Col. 71-80, real).

Note: A "New Problem Switch" card must follow the data short form also.

APPENDIX I

RPOD1 Computer Output for Illustrative Overlay Design Problem

```
RRRR    PPPP     000    DDDD     1
R   R   P   P   0   0   D   D   11
RRRR    PPPP    0   0   D   D    1
R   R   P       0   0   D   D    1
R   R   P        000    DDDD   111

NOTICE:

    THIS PAVEMENT OVERLAY DESIGN COMPUTER PROGRAM WAS DEVELOPED BY
AUSTIN RESEARCH ENGINEERS INC (2600 DELLANA LANE, AUSTIN, TEXAS  78746,
PHONE (512) 327-3520, TWX 910-874-1324 ARE INC AUS) UNDER FEDERAL
HIGHWAY ADMINISTRATION CONTRACT NO. DOT-FH-11-8544 IN AUGUST 1977.
DEVELOPMENT OF THE DESIGN PROCEDURE IS PRESENTED IN FEDERAL HIGHWAY
ADMINISTRATION REPORT NO. FHWA-RD-77-66 AND USE OF THE PROCEDURE IS
DESCRIBED IN REPORT NO. FHWA-RD-77-67.

     THIS PROGRAM REFLECTS THE VIEWS OF AUSTIN RESEARCH  ENGINEERS INC
AND NOT NECESSARILY THOSE OF THE DEPARTMENT OF TRANSPORTATION.  HOWEVER,
ANY USER OF THE PROGRAM MUST ASSUME ULTIMATE RESPONSIBILITY FOR ITS
RESULTS.
```

```
RPOD1 - RIGID PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
LATEST REVISION - JUNE 1977 - AUSTIN RESEARCH ENGINEERS INC

PROBLEM   1   ILLUSTRATIVE OVERLAY DESIGN PROBLEM, SECTION 1.


            I N P U T   V A R I A B L E S

EXISTING PAVEMENT
*****************

  CONDITION                 TYPE 1 AND 2 CRACKING WITH NO VOIDS
  CONCRETE FLEXURAL STRENGTH, PSI                          690.0
  EQUIVALENT 18 KIP SINGLE AXLE LOADS TO DATE            300000.

  LAYER  THICKNESS  POISSON/S  ELASTIC      TYPE OF
   NO.     (IN.)      RATIO    MODULUS      MATERIAL
                                (PSI)
   1        8.0        .150   4000000.        JCP
   2        7.0        .350     33000.   GRANULAR BASE
   3  SEMI-INFINITE    .450     10000.      SUBGRADE


DEFLECTION DATA
***************

  INTERIOR DESIGN DEFLECTION, INCHES             .00106
  RATIO OF CORNER TO INTERIOR DEFLECTION           1.40
  LOAD MAGNITUDE, POUNDS                          500.0
  TIRE PRESSURE, PSI                              167.0

                      X,Y COORDINATES, INCHES
  LOAD  1 LOCATION      (   0.00  ,   0.00  )
  LOAD  2 LOCATION      (  20.00  ,   0.00  )
  DEFLECTION LOCATION   (  10.00  ,   0.00  )


LABORATORY TESTS OF SUBGRADE SAMPLES
************************************


  DATA DETERMINED FROM REPETITIVE LOAD TRIAXIAL TESTING
  MEAN SUBGRADE MODULUS FOR EACH DEVIATOR STRESS.

       DEVIATOR      ELASTIC
        STRESS       MODULUS
        (PSI)         (PSI)
         3.00       123500.
         5.00        91500.
         7.00        86400.
         9.00        69500.
        11.00        67900.
```

```
OVERLAY CHARACTERISTICS
***********************


   OVERLAY TYPE                BONDED  JCP
   ELASTIC MODULUS, PSI          4000000.
   POISSON/S RATIO                    .15



DESIGN TRAFFIC
**************


   EQUIVALENT 18 KIP SINGLE AXLE LOADS ANTICIPATED ON OVERLAY.
   (TO BE USED IN CALCULATING CORRESPONDING REQUIRED OVERLAY
   THICKNESSES.)

             1            2000000.
             2            4000000.
             3            6000000.
```

```
RPOD1 - RIGID PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
LATEST REVISION - JUNE 1977 - AUSTIN RESEARCH ENGINEERS INC

PROBLEM    1   ILLUSTRATIVE OVERLAY DESIGN PROBLEM, SECTION 1.


            S Y S T E M   R E S U L T S

OVERLAY LIFE PREDICTIONS
************************

  PAVEMENT SYSTEM DESCRIPTION FOR WHICH OVERLAY LIFE
  PREDICTIONS WERE MADE.

  LAYER  THICKNESS  POISSON/S  ELASTIC       TYPE OF
   NO.     (IN.)      RATIO    MODULUS       MATERIAL
                                (PSI)
    1      VARIES      .150   4000000.         JCP
    2       8.00       .150   4000000.         JCP
    3       7.00       .350     33000.   GRANULAR BASE
    4  SEMI-INFINITE   .450      3581.       SUBGRADE

  PREDICTED LIFE OF ORIGINAL PAVEMENT
  (EQUIVALENT 18 KIP SINGLE AXLE LOADS)              708123.
  REMAINING LIFE OF ORIGINAL PAVEMENT, PERCENT          57.6

  TABLE OF OVERLAY THICKNESS VS. FATIGUE LIFE USED IN
  PLOT ON NEXT PAGE.

                  OVERLAY      CALCULATED
                 THICKNESS    FATIGUE LIFE
                   (IN.)      (EQUIVALENT
                              18 KIP SAWL)
                    3.0          1851000
                    6.0          6245000
                    9.0         17625000
                   12.0         43580000
```

```
RPOD1 - RIGID PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
LATEST REVISION - JUNE 1977 - AUSTIN RESEARCH ENGINEERS INC

PROBLEM    1   ILLUSTRATIVE OVERLAY DESIGN PROBLEM, SECTION 1.


  PLOT:
                     OVERLAY THICKNESS  VS.  FATIGUE LIFE

                          FATIGUE    LIFE    18K ESAWL
               0. 10000000. 20000000. 30000000. 40000000. 50000000.
    OVERLAY
   THICKNESS  I---------I---------I---------I---------I---------I
   (INCHES)  >                                                   <
             >                                                   <
     12.00   >                                            *      <
             >                                                   <
             >                                                   <
      9.00   >                  *                                <
             >                                                   <
             >                                                   <
      6.00   >      *                                            <
             >                                                   <
             >                                                   <
      3.00   >  *                                                <
             >                                                   <
             >                                                   <
      0.00    I---------I---------I---------I---------I---------I

           0.        1.00E+07  2.00E+07  3.00E+07  4.00E+07  5.00E+07

  TABLE OF INTERPOLATED OVERLAY THICKNESSES FOR
  REQUESTED DESIGN FATIGUE LIVES.

              FATIGUE LIFE    INTERPOLATED
              (EQUIVALENT      THICKNESS
              18 KIP SAWL)       (IN.)
                  2000000          3.2
                  4000000          4.8
                  6000000          5.9
```

```
RPOD1 - RIGID PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
LATEST REVISION - JUNE 1977 - AUSTIN RESEARCH ENGINEERS INC

PROBLEM   2   ILLUSTRATIVE OVERLAY DESIGN PROBLEM, SECTION 1.


            I N P U T   V A R I A B L E S

EXISTING PAVEMENT
*****************

  CONDITION                   TYPE 1 AND 2 CRACKING WITH NO VOIDS
  CONCRETE FLEXURAL STRENGTH, PSI                           690.0
  EQUIVALENT 18 KIP SINGLE AXLE LOADS TO DATE             300000.

  LAYER  THICKNESS  POISSON/S  ELASTIC       TYPE OF
   NO.     (IN.)      RATIO    MODULUS       MATERIAL
                                (PSI)
    1       8.0       .150   4000000.         JCP
    2       7.0       .350     33000.    GRANULAR BASE
    3  SEMI-INFINITE  .450      3581.       SUBGRADE


DEFLECTION DATA
***************

  INTERIOR DESIGN DEFLECTION, INCHES            .00106
  RATIO OF CORNER TO INTERIOR DEFLECTION          1.40
  LOAD MAGNITUDE, POUNDS                         500.0
  TIRE PRESSURE, PSI                             167.0

                          X,Y COORDINATES, INCHES
  LOAD  1 LOCATION       (   0.00  ,    0.00  )
  LOAD  2 LOCATION       (  20.00  ,    0.00  )
  DEFLECTION LOCATION    (  10.00  ,    0.00  )


LABORATORY TESTS OF SUBGRADE SAMPLES
************************************


  DATA DETERMINED FROM REPETITIVE LOAD TRIAXIAL TESTING
  MEAN SUBGRADE MODULUS FOR EACH DEVIATOR STRESS.

        DEVIATOR     ELASTIC
         STRESS      MODULUS
         (PSI)        (PSI)
          3.00       123500.
          5.00        91500.
          7.00        86400.
          9.00        69500.
         11.00        67900.
```

```
OVERLAY CHARACTERISTICS
***********************


  OVERLAY TYPE                          AC
  ELASTIC MODULUS, PSI             450000.
  POISSON/S RATIO                      .30


DESIGN TRAFFIC
**************


  EQUIVALENT 18 KIP SINGLE AXLE LOADS ANTICIPATED ON OVERLAY.
  (TO BE USED IN CALCULATING CORRESPONDING REQUIRED OVERLAY
  THICKNESSES.)

          1          2000000.
          2          4000000.
          3          6000000.
```

```
RPOD1 - RIGID PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
LATEST REVISION - JUNE 1977 - AUSTIN RESEARCH ENGINEERS INC

PROBLEM   2   ILLUSTRATIVE OVERLAY DESIGN PROBLEM, SECTION 1.


            S Y S T E M   R E S U L T S

OVERLAY LIFE PREDICTIONS
************************

  PAVEMENT SYSTEM DESCRIPTION FOR WHICH OVERLAY LIFE
  PREDICTIONS WERE MADE.

  LAYER  THICKNESS  POISSON/S  ELASTIC      TYPE OF
   NO.     (IN.)      RATIO    MODULUS      MATERIAL
                                (PSI)
    1      VARIES      .300    450000.         AC
    2       8.00       .150   4000000.        JCP
    3       7.00       .350     33000.   GRANULAR BASE
    4  SEMI-INFINITE   .450      3581.      SUBGRADE


  PREDICTED LIFE OF ORIGINAL PAVEMENT
  (EQUIVALENT 18 KIP SINGLE AXLE LOADS)            708123.
  REMAINING LIFE OF ORIGINAL PAVEMENT, PERCENT        57.6


  TABLE OF OVERLAY THICKNESS VS. FATIGUE LIFE USED IN
  PLOT ON NEXT PAGE.

                 OVERLAY      CALCULATED
                THICKNESS    FATIGUE LIFE
                  (IN.)      (EQUIVALENT
                             18 KIP SAWL)
                    3.0          689000
                    6.0         1459000
                    9.0         3117000
                   12.0         6427000
```

```
RPOD1 - RIGID PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
LATEST REVISION - JUNE 1977 - AUSTIN RESEARCH ENGINEERS INC

PROBLEM   2   ILLUSTRATIVE OVERLAY DESIGN PROBLEM, SECTION 1.


  PLOT:
                     OVERLAY THICKNESS  VS.  FATIGUE LIFE

                          FATIGUE    LIFE    18K ESAWL
               0.  2000000.  4000000.  6000000.  8000000. 10000000.
    OVERLAY
   THICKNESS  I---------I---------I---------I---------I---------I
   (INCHES)  >                                                   <
             >                                                   <
     12.00   >                                *                  <
             >                                                   <
             >                                                   <
      9.00   >                *                                  <
             >                                                   <
             >                                                   <
      6.00   >       *                                           <
             >                                                   <
             >                                                   <
      3.00   >   *                                               <
             >                                                   <
             >                                                   <
      0.00    I---------I---------I---------I---------I---------I

           0.         2.00E+06  4.00E+06  6.00E+06  8.00E+06  1.00E+07


  TABLE OF INTERPOLATED OVERLAY THICKNESSES FOR
  REQUESTED DESIGN FATIGUE LIVES.

              FATIGUE LIFE    INTERPOLATED
              (EQUIVALENT      THICKNESS
              18 KIP SAWL)       (IN.)
                  2000000          7.3
                  4000000         10.0
                  6000000         11.7
```

```
RPOD1 - RIGID PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
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PROBLEM   3   ILLUSTRATIVE OVERLAY DESIGN PROBLEM, SECTION 2.


              I N P U T   V A R I A B L E S

EXISTING PAVEMENT
*****************

  CONDITION                     TYPE 1 AND 2 CRACKING WITH NO VOIDS
  CONCRETE FLEXURAL STRENGTH, PSI                             690.0
  EQUIVALENT 18 KIP SINGLE AXLE LOADS TO DATE              300000.

  LAYER  THICKNESS  POISSON/S  ELASTIC      TYPE OF
   NO.     (IN.)      RATIO    MODULUS      MATERIAL
                                (PSI)
    1       8.0       .150    4000000.        JCP
    2       6.0       .350      18000.   GRANULAR BASE
    3       6.0       .400      12000.   GRANULAR BASE
    4   SEMI-INFINITE  .450     10000.      SUBGRADE


DEFLECTION DATA
***************

  INTERIOR DESIGN DEFLECTION, INCHES            .00060
  RATIO OF CORNER TO INTERIOR DEFLECTION          1.40
  LOAD MAGNITUDE, POUNDS                         500.0
  TIRE PRESSURE, PSI                             167.0

                        X,Y COORDINATES, INCHES
  LOAD  1 LOCATION      (   0.00  ,    0.00  )
  LOAD  2 LOCATION      (  20.00  ,    0.00  )
  DEFLECTION LOCATION   (  10.00  ,    0.00  )


LABORATORY TESTS OF SUBGRADE SAMPLES
************************************


  DATA DETERMINED FROM REPETITIVE LOAD TRIAXIAL TESTING
  MEAN SUBGRADE MODULUS FOR EACH DEVIATOR STRESS.

        DEVIATOR      ELASTIC
         STRESS       MODULUS
         (PSI)         (PSI)
          3.00       136200.
          5.00        73600.
          7.00        56900.
          9.00        44000.
         11.00        32600.
```

```
OVERLAY CHARACTERISTICS
***********************

  OVERLAY TYPE                 BONDED  JCP
  ELASTIC MODULUS, PSI           4000000.
  POISSON/S RATIO                     .15

DESIGN TRAFFIC
**************

  EQUIVALENT 18 KIP SINGLE AXLE LOADS ANTICIPATED ON OVERLAY.
  (TO BE USED IN CALCULATING CORRESPONDING REQUIRED OVERLAY
  THICKNESSES.)

          1           2000000.
          2           4000000.
          3           6000000.
```

```
RPOD1 - RIGID PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
LATEST REVISION - JUNE 1977 - AUSTIN RESEARCH ENGINEERS INC

PROBLEM   3   ILLUSTRATIVE OVERLAY DESIGN PROBLEM, SECTION 2.


            S Y S T E M   R E S U L T S

OVERLAY LIFE PREDICTIONS
************************

  PAVEMENT SYSTEM DESCRIPTION FOR WHICH OVERLAY LIFE
  PREDICTIONS WERE MADE.

  LAYER  THICKNESS  POISSON/S  ELASTIC      TYPE OF
   NO.     (IN.)      RATIO    MODULUS      MATERIAL
                                (PSI)
    1      VARIES      .150   4000000.        JCP
    2       8.00       .150   4000000.        JCP
    3       6.00       .350     18000.   GRANULAR BASE
    4       6.00       .400     12000.   GRANULAR BASE
    5  SEMI-INFINITE   .450      4009.      SUBGRADE


  PREDICTED LIFE OF ORIGINAL PAVEMENT
  (EQUIVALENT 18 KIP SINGLE AXLE LOADS)            729487.
  REMAINING LIFE OF ORIGINAL PAVEMENT, PERCENT        58.9


  TABLE OF OVERLAY THICKNESS VS. FATIGUE LIFE USED IN
  PLOT ON NEXT PAGE.

                 OVERLAY      CALCULATED
                THICKNESS    FATIGUE LIFE
                  (IN.)      (EQUIVALENT
                             18 KIP SAWL)
                    3.0          1973000
                    6.0          6642000
                    9.0         18658000
                   12.0         46002000
```

```
RPOD1 - RIGID PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
LATEST REVISION - JUNE 1977 - AUSTIN RESEARCH ENGINEERS INC

PROBLEM    3   ILLUSTRATIVE OVERLAY DESIGN PROBLEM, SECTION 2.


   PLOT:
                      OVERLAY THICKNESS  VS.  FATIGUE LIFE

                           FATIGUE   LIFE    18K ESAWL
                0. 10000000. 20000000. 30000000. 40000000. 50000000.
    OVERLAY
   THICKNESS   I---------I---------I---------I---------I---------I
    (INCHES)  >                                                   <
              >                                                   <
      12.00   >                                              *    <
              >                                                   <
              >                                                   <
       9.00   >                   *                               <
              >                                                   <
              >                                                   <
       6.00   >       *                                           <
              >                                                   <
              >                                                   <
       3.00   >  *                                                <
              >                                                   <
              >                                                   <
       0.00    I---------I---------I---------I---------I---------I

            0.         1.00E+07  2.00E+07  3.00E+07  4.00E+07  5.00E+07

   TABLE OF INTERPOLATED OVERLAY THICKNESSES FOR
   REQUESTED DESIGN FATIGUE LIVES.

               FATIGUE LIFE    INTERPOLATED
               (EQUIVALENT      THICKNESS
               18 KIP SAWL)       (IN.)
                   2000000          3.0
                   4000000          4.7
                   6000000          5.7
```

```
RPOD1 - RIGID PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
LATEST REVISION - JUNE 1977 - AUSTIN RESEARCH ENGINEERS INC

PROBLEM   4   ILLUSTRATIVE OVERLAY DESIGN PROBLEM, SECTION 2.


              I N P U T   V A R I A B L E S

EXISTING PAVEMENT
*****************


  CONDITION                      TYPE 1 AND 2 CRACKING WITH NO VOIDS
  CONCRETE FLEXURAL STRENGTH, PSI                              690.0
  EQUIVALENT 18 KIP SINGLE AXLE LOADS TO DATE                300000.

  LAYER  THICKNESS  POISSON/S  ELASTIC      TYPE OF
   NO.     (IN.)      RATIO    MODULUS      MATERIAL
                                (PSI)
    1       8.0       .150   4000000.         JCP
    2       6.0       .350     18000.    GRANULAR BASE
    3       6.0       .400     12000.    GRANULAR BASE
    4  SEMI-INFINITE  .450      4009.       SUBGRADE


DEFLECTION DATA
***************

  INTERIOR DESIGN DEFLECTION, INCHES              .00060
  RATIO OF CORNER TO INTERIOR DEFLECTION            1.40
  LOAD MAGNITUDE, POUNDS                           500.0
  TIRE PRESSURE, PSI                               167.0

                         X,Y COORDINATES, INCHES
  LOAD  1 LOCATION      (    0.00  ,    0.00  )
  LOAD  2 LOCATION      (   20.00  ,    0.00  )
  DEFLECTION LOCATION   (   10.00  ,    0.00  )


LABORATORY TESTS OF SUBGRADE SAMPLES
************************************


  DATA DETERMINED FROM REPETITIVE LOAD TRIAXIAL TESTING
  MEAN SUBGRADE MODULUS FOR EACH DEVIATOR STRESS.

        DEVIATOR      ELASTIC
         STRESS       MODULUS
         (PSI)         (PSI)
          3.00       136200.
          5.00        73600.
          7.00        56900.
          9.00        44000.
         11.00        32600.
```

```
OVERLAY CHARACTERISTICS
***********************

  OVERLAY TYPE                        AC
  ELASTIC MODULUS, PSI           450000.
  POISSON/S RATIO                    .30


DESIGN TRAFFIC
**************

  EQUIVALENT 18 KIP SINGLE AXLE LOADS ANTICIPATED ON OVERLAY.
  (TO BE USED IN CALCULATING CORRESPONDING REQUIRED OVERLAY
  THICKNESSES.)

          1         2000000.
          2         4000000.
          3         6000000.
```

```
RPOD1 - RIGID PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
LATEST REVISION - JUNE 1977 - AUSTIN RESEARCH ENGINEERS INC

PROBLEM   4   ILLUSTRATIVE OVERLAY DESIGN PROBLEM, SECTION 2.


           S Y S T E M   R E S U L T S

OVERLAY LIFE PREDICTIONS
************************


  PAVEMENT SYSTEM DESCRIPTION FOR WHICH OVERLAY LIFE
  PREDICTIONS WERE MADE.

  LAYER  THICKNESS  POISSON/S  ELASTIC       TYPE OF
   NO.     (IN.)      RATIO    MODULUS       MATERIAL
                                (PSI)
    1     VARIES      .300    450000.          AC
    2      8.00       .150   4000000.          JCP
    3      6.00       .350     18000.   GRANULAR BASE
    4      6.00       .400     12000.   GRANULAR BASE
    5  SEMI-INFINITE  .450      4009.      SUBGRADE


  PREDICTED LIFE OF ORIGINAL PAVEMENT
  (EQUIVALENT 18 KIP SINGLE AXLE LOADS)           729487.
  REMAINING LIFE OF ORIGINAL PAVEMENT, PERCENT        58.9


  TABLE OF OVERLAY THICKNESS VS. FATIGUE LIFE USED IN
  PLOT ON NEXT PAGE.

                 OVERLAY      CALCULATED
                THICKNESS    FATIGUE LIFE
                  (IN.)      (EQUIVALENT
                             18 KIP SAWL)
                   3.0          733000
                   6.0         1560000
                   9.0         3332000
                  12.0         6843000
```

```
RPOD1 - RIGID PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
LATEST REVISION - JUNE 1977 - AUSTIN RESEARCH ENGINEERS INC

PROBLEM   4   ILLUSTRATIVE OVERLAY DESIGN PROBLEM, SECTION 2.


  PLOT:
                     OVERLAY THICKNESS  VS.  FATIGUE LIFE

                          FATIGUE    LIFE    18K ESAWL
               0.  2000000.  4000000.  6000000.  8000000. 10000000.
    OVERLAY
   THICKNESS  I---------I---------I---------I---------I---------I
   (INCHES)  >                                                   <
             >                                                   <
     12.00   >                                  *                <
             >                                                   <
             >                                                   <
      9.00   >                 *                                 <
             >                                                   <
             >                                                   <
      6.00   >        *                                          <
             >                                                   <
             >                                                   <
      3.00   >    *                                              <
             >                                                   <
             >                                                   <
      0.00    I---------I---------I---------I---------I---------I

           0.        2.00E+06  4.00E+06  6.00E+06  8.00E+06  1.00E+07

  TABLE OF INTERPOLATED OVERLAY THICKNESSES FOR
  REQUESTED DESIGN FATIGUE LIVES.

              FATIGUE LIFE    INTERPOLATED
              (EQUIVALENT      THICKNESS
              18 KIP SAWL)        (IN.)
                  2000000          7.0
                  4000000          9.7
                  6000000         11.4
```

```
RPOD1 - RIGID PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
LATEST REVISION - JUNE 1977 - AUSTIN RESEARCH ENGINEERS INC

PROBLEM   5   ILLUSTRATIVE OVERLAY DESIGN PROBLEM, SECTION 3.


           I N P U T   V A R I A B L E S

EXISTING PAVEMENT
*****************


  CONDITION                     TYPE 1 AND 2 CRACKING WITH NO VOIDS
  CONCRETE FLEXURAL STRENGTH, PSI                             690.0
  EQUIVALENT 18 KIP SINGLE AXLE LOADS TO DATE               300000.

  LAYER  THICKNESS  POISSON/S  ELASTIC      TYPE OF
   NO.     (IN.)      RATIO    MODULUS      MATERIAL
                                (PSI)
    1       8.0       .150    4000000.        JCP
    2       7.0       .350      33000.   GRANULAR BASE
    3   SEMI-INFINITE .450      50000.      SUBGRADE


DEFLECTION DATA
***************


  INTERIOR DESIGN DEFLECTION, INCHES           .00092
  RATIO OF CORNER TO INTERIOR DEFLECTION         1.40
  LOAD MAGNITUDE, POUNDS                        500.0
  TIRE PRESSURE, PSI                            167.0

                         X,Y COORDINATES, INCHES
  LOAD  1 LOCATION      (   0.00  ,   0.00  )
  LOAD  2 LOCATION      (  20.00  ,   0.00  )
  DEFLECTION LOCATION   (  10.00  ,   0.00  )


LABORATORY TESTS OF SUBGRADE SAMPLES
************************************


  DATA DETERMINED FROM REPETITIVE LOAD TRIAXIAL TESTING
  MEAN SUBGRADE MODULUS FOR EACH DEVIATOR STRESS.

      DEVIATOR       ELASTIC
       STRESS        MODULUS
       (PSI)          (PSI)
        5.00         38200.
        7.00         35700.
        9.00         31000.
```

```
OVERLAY CHARACTERISTICS
***********************

  OVERLAY TYPE                BONDED  JCP
  ELASTIC MODULUS, PSI          4000000.
  POISSON/S RATIO                    .15


DESIGN TRAFFIC
**************

  EQUIVALENT 18 KIP SINGLE AXLE LOADS ANTICIPATED ON OVERLAY.
  (TO BE USED IN CALCULATING CORRESPONDING REQUIRED OVERLAY
  THICKNESSES.)

           1         2000000.
           2         4000000.
           3         6000000.
```

```
RPOD1 - RIGID PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
LATEST REVISION - JUNE 1977 - AUSTIN RESEARCH ENGINEERS INC

PROBLEM   5   ILLUSTRATIVE OVERLAY DESIGN PROBLEM, SECTION 3.


              S Y S T E M   R E S U L T S

OVERLAY LIFE PREDICTIONS
************************

  PAVEMENT SYSTEM DESCRIPTION FOR WHICH OVERLAY LIFE
  PREDICTIONS WERE MADE.

  LAYER  THICKNESS  POISSON/S  ELASTIC      TYPE OF
   NO.     (IN.)      RATIO    MODULUS      MATERIAL
                                (PSI)
    1      VARIES      .150   4000000.        JCP
    2       8.00       .150   4000000.        JCP
    3       7.00       .350     33000.   GRANULAR BASE
    4   SEMI-INFINITE  .450      5241.      SUBGRADE


  PREDICTED LIFE OF ORIGINAL PAVEMENT
  (EQUIVALENT 18 KIP SINGLE AXLE LOADS)            875231.
  REMAINING LIFE OF ORIGINAL PAVEMENT, PERCENT        65.7


  TABLE OF OVERLAY THICKNESS VS. FATIGUE LIFE USED IN
  PLOT ON NEXT PAGE.

                  OVERLAY      CALCULATED
                 THICKNESS    FATIGUE LIFE
                   (IN.)      (EQUIVALENT
                              18 KIP SAWL)
                    3.0          2621000
                    6.0          8665000
                    9.0         23875000
                   12.0         58060000
```

```
RPOD1 - RIGID PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
LATEST REVISION - JUNE 1977 - AUSTIN RESEARCH ENGINEERS INC

PROBLEM   5   ILLUSTRATIVE OVERLAY DESIGN PROBLEM, SECTION 3.


  PLOT:
                     OVERLAY THICKNESS  VS.  FATIGUE LIFE

                          FATIGUE    LIFE    18K ESAWL
               0. 20000000. 40000000. 60000000. 80000000.100000000.
    OVERLAY
   THICKNESS  I---------I---------I---------I---------I---------I
   (INCHES)  >                                                   <
             >                                                   <
     12.00   >                             *                     <
             >                                                   <
             >                                                   <
      9.00   >            *                                      <
             >                                                   <
             >                                                   <
      6.00   >    *                                              <
             >                                                   <
             >                                                   <
      3.00   > *                                                 <
             >                                                   <
             >                                                   <
      0.00    I---------I---------I---------I---------I---------I

           0.        2.00E+07  4.00E+07  6.00E+07  8.00E+07  1.00E+08

  TABLE OF INTERPOLATED OVERLAY THICKNESSES FOR
  REQUESTED DESIGN FATIGUE LIVES.

              FATIGUE LIFE    INTERPOLATED
              (EQUIVALENT      THICKNESS
              18 KIP SAWL)       (IN.)
                  2000000          2.3*
                  4000000          4.0
                  6000000          5.0

  * NOTE:  THE THICKNESS DERIVED BY EXTRAPOLATION FOR THIS DESIGN
           LIFE IS LESS THAN THE 3-INCH MINIMUM RECOMMENDED FOR
           STRUCTURAL REHABILITATION.  USE A LARGER DESIGN LIFE
           TO AVOID EXTRAPOLATION BEYOND THE RANGE OF THE DATA.
```

```
RPOD1 - RIGID PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
LATEST REVISION - JUNE 1977 - AUSTIN RESEARCH ENGINEERS INC

PROBLEM   6   ILUUSTRATIVE OVERLAY DESIGN PROBLEM, SECTION 3.


           I N P U T   V A R I A B L E S

EXISTING PAVEMENT
*****************


  CONDITION                      TYPE 1 AND 2 CRACKING WITH NO VOIDS
  CONCRETE FLEXURAL STRENGTH, PSI                               690.0
  EQUIVALENT 18 KIP SINGLE AXLE LOADS TO DATE                 300000.

  LAYER  THICKNESS  POISSON/S  ELASTIC       TYPE OF
   NO.     (IN.)      RATIO    MODULUS       MATERIAL
                                (PSI)
    1        8.0       .150   4000000.         JCP
    2        7.0       .350     33000.   GRANULAR BASE
    3  SEMI-INFINITE   .450      5241.       SUBGRADE


DEFLECTION DATA
***************


  INTERIOR DESIGN DEFLECTION, INCHES          .00092
  RATIO OF CORNER TO INTERIOR DEFLECTION        1.40
  LOAD MAGNITUDE, POUNDS                       500.0
  TIRE PRESSURE, PSI                           167.0

                         X,Y COORDINATES, INCHES
  LOAD  1 LOCATION      (   0.00   ,   0.00  )
  LOAD  2 LOCATION      (  20.00   ,   0.00  )
  DEFLECTION LOCATION   (  10.00   ,   0.00  )


LABORATORY TESTS OF SUBGRADE SAMPLES
************************************


  DATA DETERMINED FROM REPETITIVE LOAD TRIAXIAL TESTING
  MEAN SUBGRADE MODULUS FOR EACH DEVIATOR STRESS.

      DEVIATOR     ELASTIC
       STRESS      MODULUS
       (PSI)        (PSI)
        5.00       38200.
        7.00       35700.
        9.00       31000.
```

```
OVERLAY CHARACTERISTICS
***********************

  OVERLAY TYPE                           AC
  ELASTIC MODULUS, PSI              450000.
  POISSON/S RATIO                       .30

DESIGN TRAFFIC
**************

  EQUIVALENT 18 KIP SINGLE AXLE LOADS ANTICIPATED ON OVERLAY.
  (TO BE USED IN CALCULATING CORRESPONDING REQUIRED OVERLAY
  THICKNESSES.)

          1          2000000.
          2          4000000.
          3          6000000.
```

```
STRESS AND LOCATION AND VOID FACTORS FOR
REMAINING LIFE CALCULATION       .153E+03 1.46 1.00

OVLIFE PARAMETERS
NOVL,LAYR,FLOC,REM=    1    2   1.500     .657

PAVEMENT SYSTEM FOR WHICH
OVERLAY LIFE PREDICTIONS MADE

 LAYER  MODULUS    POISSONS   THICKNESS
                    RATIO      (INCHES)
   1     450000.     .30
   2    4000000.     .15          8.0
   3      33000.     .35          7.0
   4       5241.     .45          0.0

CRITICAL STRESS AT BOTTOM OF LAYER  2 AND EXPECTED LIFETIME
    OVERLAY THICKNESS  STRESS (PSI)      LOAD APPLICATIONS

          12.0            .631E+02             .904E+07
           9.0            .787E+02             .446E+07
           6.0            .994E+02             .211E+07
           3.0            .126E+03             .989E+06
```

```
RPOD1 - RIGID PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
LATEST REVISION - JUNE 1977 - AUSTIN RESEARCH ENGINEERS INC

PROBLEM   6   ILLUSTRATIVE OVERLAY DESIGN PROBLEM, SECTION 3.


            S Y S T E M   R E S U L T S

OVERLAY LIFE PREDICTIONS
************************

  PAVEMENT SYSTEM DESCRIPTION FOR WHICH OVERLAY LIFE
  PREDICTIONS WERE MADE.

  LAYER  THICKNESS  POISSON/S  ELASTIC       TYPE OF
   NO.     (IN.)      RATIO    MODULUS       MATERIAL
                                (PSI)
    1      VARIES      .300    450000.          AC
    2       8.00       .150   4000000.          JCP
    3       7.00       .350     33000.    GRANULAR BASE
    4   SEMI-INFINITE  .450      5241.        SUBGRADE


  PREDICTED LIFE OF ORIGINAL PAVEMENT
  (EQUIVALENT 18 KIP SINGLE AXLE LOADS)              875231.
  REMAINING LIFE OF ORIGINAL PAVEMENT, PERCENT          65.7


  TABLE OF OVERLAY THICKNESS VS. FATIGUE LIFE USED IN
  PLOT ON NEXT PAGE.

                    OVERLAY       CALCULATED
                   THICKNESS     FATIGUE LIFE
                     (IN.)       (EQUIVALENT
                                 18 KIP SAWL)
                      3.0           989000
                      6.0          2107000
                      9.0          4461000
                     12.0          9041000
```

```
     RPOD1 - RIGID PAVEMENT OVERLAY DESIGN PROGRAM - VERSION 1.0
     LATEST REVISION - JUNE 1977 - AUSTIN RESEARCH ENGINEERS INC

     PROBLEM   6   ILUUSTRATIVE OVERLAY DESIGN PROBLEM, SECTION 3.


       PLOT:
                          OVERLAY THICKNESS  VS.  FATIGUE LIFE

                               FATIGUE    LIFE    18K ESAWL
                    0.  2000000.  4000000.  6000000.  8000000. 10000000.
         OVERLAY
        THICKNESS  I---------I---------I---------I---------I---------I
        (INCHES)  >                                                   <
                  >                                                   <
         12.00    >                                             *     <
                  >                                                   <
                  >                                                   <
          9.00    >                      *                            <
                  >                                                   <
                  >                                                   <
          6.00    >           *                                       <
                  >                                                   <
                  >                                                   <
          3.00    >     *                                             <
                  >                                                   <
                  >                                                   <
          0.00     I---------I---------I---------I---------I---------I

                0.        2.00E+06  4.00E+06  6.00E+06  8.00E+06  1.00E+07

       TABLE OF INTERPOLATED OVERLAY THICKNESSES FOR
       REQUESTED DESIGN FATIGUE LIVES.

                   FATIGUE LIFE     INTERPOLATED
                   (EQUIVALENT       THICKNESS
                   18 KIP SAWL)        (IN.)
                       2000000            5.8
                       4000000            8.6
                       6000000           10.2
```

APPENDIX J

RFLCR1 Computer Output for Illustrative Overlay Design Problem

```
*********************************************************************
     REFLECTION CRACKING INPUT VARIABLES
*********************************************************************


          *********************
          * EXISTING PAVEMENT *
          *********************

LOCATION
ILUUSTRATIVE EXAMPLE PROBLEM
ASPHALTIC CONCRETE OVERLAY W/BOND BREAKER ON JOINTED CONCRETE PAVT.

PAVEMENT TYPE                             JCP
   CONDITION                        UNCRACKED
   JOINT SPACING, FT                    20.00

PAVEMENT PROPERTIES
   MODULUS, PSI                      4000000.
   THICKNESS, INCHES                     8.00
   DENSITY, PCF                         148.0
   THERMAL COEFFICIENT, PER DEGREE F .0000060

PAVEMENT MOVEMENT AT SLIDING, INCHES    .2500


          ********************
          * CHARACTERIZATION *
          ********************

HORIZONTAL
   HIGH TEMPERATURE, DEGREES F           95.0
   HIGH TEMPERATURE JOINT WIDTH, INCHES .18970
   LOW TEMPERATURE, DEGREES F            73.0
   LOW TEMPERATURE JOINT WIDTH, INCHES  .20800
   MIN. TEMPERATURE OBSERVED, DEGREES F   -20.

VERTICAL
   JOINT WIDTH, INCHES                   .190
   LOAD TRANSFER, PERCENT                78.0
```

```
                    ***********
                    * OVERLAY *
                    ***********

OVERLAY TYPE                                       AC

   CREEP MODULUS, PSI                          350000.
   DYNAMIC MODULUS, PSI                       4000000.
   THICKNESS, INCHES                             12.00
   DENSITY, PCF                                  140.0
   POISSONS RATIO                                 .300
   THERMAL COEFFICIENT, PER DEGREE F          .0000120
   BONDING STRESS, PSI                           500.0

NOTE - SLOPE OF FRICTION CURVE FOR INTERFACE BENEATH EXISTING
       PAVEMENT WILL BE MULTIPLIED BY RATIO OF NEW OVERBURDEN
       WEIGHT TO EXISTING OVERBURDEN WEIGHT.


              ***********************
              * OTHER DESIGN INPUTS *
              ***********************

DESIGN TEMPERATURE CHANGES, DEGREES F
   EXISTING PAVEMENT                              100.
   OVERLAY                                        120.

DESIGN LOAD
   WEIGHT, POUNDS                              24000.0
   WIDTH, INCHES                                  24.0
```

```
**********************************************************************
     REFLECTION CRACKING PROGRAM OUTPUT
**********************************************************************

            ***************
            * BETA VALUES *
            ***************

   BEFORE OVERLAY                        .8531
   AFTER OVERLAY
     BONDED                              .9506

       ***************************
       * SLOPE OF FRICTION CURVE *
       ***************************

   BEFORE OVERLAY                     .414E+05
   AFTER OVERLAY                      .100E+06

        ************************
        *   MAXIMUM STRESSES   *
        * IN EXISTING PAVEMENT *
        *        (PSI)         *
        ************************

   CONCRETE, BEFORE OVERLAY              223.0

          *********************
          *********************
          ** OVERLAY STRAINS **
          **      IN/IN      **
          *********************
          *********************

   SHEAR                              .119E-04
   TENSILE                            .274E-02
```

```
**************************************************************************
     REFLECTION CRACKING INPUT VARIABLES
**************************************************************************


          *********************
          * EXISTING PAVEMENT *
          *********************


LOCATION
ILLUSTRATIVE EXAMPLE PROBLEM
ASPHALTIC CONCRETE OVERLAY W/BOND BREAKER ON JOINTED CONCRETE PAVT.

PAVEMENT TYPE                                    JCP
   CONDITION                               UNCRACKED
   JOINT SPACING, FT                           20.00

PAVEMENT PROPERTIES
   MODULUS, PSI                             4000000.
   THICKNESS, INCHES                            8.00
   DENSITY, PCF                                148.0
   THERMAL COEFFICIENT, PER DEGREE F        .0000060

PAVEMENT MOVEMENT AT SLIDING, INCHES           .2500


          ********************
          * CHARACTERIZATION *
          ********************


HORIZONTAL
   HIGH TEMPERATURE, DEGREES F                  95.0
   HIGH TEMPERATURE JOINT WIDTH, INCHES       .18970
   LOW TEMPERATURE, DEGREES F                   73.0
   LOW TEMPERATURE JOINT WIDTH, INCHES        .20800
   MIN. TEMPERATURE OBSERVED, DEGREES F         -20.

VERTICAL
   JOINT WIDTH, INCHES                          .190
   LOAD TRANSFER, PERCENT                       78.0
```

```
                 ***********
                 * OVERLAY *
                 ***********

OVERLAY TYPE                                   AC

   CREEP MODULUS, PSI                      350000.
   DYNAMIC MODULUS, PSI                   4000000.
   THICKNESS, INCHES                         12.00
   DENSITY, PCF                              140.0
   POISSONS RATIO                             .300
   THERMAL COEFFICIENT, PER DEGREE F      .0000120
   BONDING STRESS, PSI                       500.0

NOTE - SLOPE OF FRICTION CURVE FOR INTERFACE BENEATH EXISTING
       PAVEMENT WILL BE MULTIPLIED BY RATIO OF NEW OVERBURDEN
       WEIGHT TO EXISTING OVERBURDEN WEIGHT.

BOND BREAKER WIDTH, FEET                       1.0


           ***********************
           * OTHER DESIGN INPUTS *
           ***********************

DESIGN TEMPERATURE CHANGES, DEGREES F
   EXISTING PAVEMENT                          100.
   OVERLAY                                    120.

DESIGN LOAD
   WEIGHT, POUNDS                          24000.0
   WIDTH, INCHES                              24.0
```

```
**********************************************************************
     REFLECTION CRACKING PROGRAM OUTPUT
**********************************************************************


            ***************
            * BETA VALUES *
            ***************


   BEFORE OVERLAY                                  .8531
   AFTER OVERLAY
     BONDED                                        .9457
     UNBONDED                                      .9223


       ***************************
       * SLOPE OF FRICTION CURVE *
       ***************************


   BEFORE OVERLAY                               .414E+05
   AFTER OVERLAY                                .100E+06


        ************************
        *   MAXIMUM STRESSES   *
        * IN EXISTING PAVEMENT *
        *        (PSI)         *
        ************************


   CONCRETE, BEFORE OVERLAY                        223.0


          *********************
          *********************
          ** OVERLAY STRAINS **
          **      IN/IN      **
          *********************
          *********************


   SHEAR                                        .119E-04
   TENSILE                                      .247E-02
```

```
**********************************************************************
     REFLECTION CRACKING INPUT VARIABLES
**********************************************************************


          *********************
          * EXISTING PAVEMENT *
          *********************


LOCATION
ILLUSTRATIVE EXAMPLE PROBLEM
ASPHALTIC CONCRETE OVERLAY W/BOND BREAKER ON JOINTED CONCRETE PAVT.

PAVEMENT TYPE                              JCP
   CONDITION                         UNCRACKED
   JOINT SPACING, FT                     20.00

PAVEMENT PROPERTIES
   MODULUS, PSI                       4000000.
   THICKNESS, INCHES                      8.00
   DENSITY, PCF                          148.0
   THERMAL COEFFICIENT, PER DEGREE F  .0000060

PAVEMENT MOVEMENT AT SLIDING, INCHES     .2500


          ********************
          * CHARACTERIZATION *
          ********************


HORIZONTAL
   HIGH TEMPERATURE, DEGREES F            95.0
   HIGH TEMPERATURE JOINT WIDTH, INCHES .18970
   LOW TEMPERATURE, DEGREES F             73.0
   LOW TEMPERATURE JOINT WIDTH, INCHES  .20800
   MIN. TEMPERATURE OBSERVED, DEGREES F   -20.

VERTICAL
   JOINT WIDTH, INCHES                    .190
   LOAD TRANSFER, PERCENT                 78.0
```

```
                 ***********
                 * OVERLAY *
                 ***********

   OVERLAY TYPE                                         AC

      CREEP MODULUS, PSI                             350000.
      DYNAMIC MODULUS, PSI                          4000000.
      THICKNESS, INCHES                                12.00
      DENSITY, PCF                                     140.0
      POISSONS RATIO                                    .300
      THERMAL COEFFICIENT, PER DEGREE F             .0000120
      BONDING STRESS, PSI                              500.0

   NOTE - SLOPE OF FRICTION CURVE FOR INTERFACE BENEATH EXISTING
          PAVEMENT WILL BE MULTIPLIED BY RATIO OF NEW OVERBURDEN
          WEIGHT TO EXISTING OVERBURDEN WEIGHT.

   BOND BREAKER WIDTH, FEET                              2.0


             ***********************
             * OTHER DESIGN INPUTS *
             ***********************

   DESIGN TEMPERATURE CHANGES, DEGREES F
      EXISTING PAVEMENT                                 100.
      OVERLAY                                           120.

   DESIGN LOAD
      WEIGHT, POUNDS                                 24000.0
      WIDTH, INCHES                                     24.0
```

```
**********************************************************************
     REFLECTION CRACKING PROGRAM OUTPUT
**********************************************************************


            ***************
            * BETA VALUES *
            ***************

   BEFORE OVERLAY                          .8531
   AFTER OVERLAY
     BONDED                                .9415
     UNBONDED                              .9223


       ***************************
       * SLOPE OF FRICTION CURVE *
       ***************************

   BEFORE OVERLAY                       .414E+05
   AFTER OVERLAY                        .100E+06


        *************************
        *   MAXIMUM STRESSES    *
        * IN EXISTING PAVEMENT  *
        *        (PSI)          *
        *************************

   CONCRETE, BEFORE OVERLAY                223.0


          **********************
          **********************
          ** OVERLAY STRAINS  **
          **      IN/IN       **
          **********************
          **********************

   SHEAR                                .119E-04
   TENSILE                              .226E-02
```

```
***********************************************************************
     REFLECTION CRACKING INPUT VARIABLES
***********************************************************************


          *********************
          * EXISTING PAVEMENT *
          *********************

LOCATION
ILLUSTRATIVE EXAMPLE PROBLEM
ASPHALTIC CONCRETE OVERLAY W/BOND BREAKER ON JOINTED CONCRETE PAVT.

PAVEMENT TYPE                               JCP
   CONDITION                          UNCRACKED
   JOINT SPACING, FT                      20.00

PAVEMENT PROPERTIES
   MODULUS, PSI                        4000000.
   THICKNESS, INCHES                       8.00
   DENSITY, PCF                           148.0
   THERMAL COEFFICIENT, PER DEGREE F   .0000060

PAVEMENT MOVEMENT AT SLIDING, INCHES      .2500


          ********************
          * CHARACTERIZATION *
          ********************

HORIZONTAL
   HIGH TEMPERATURE, DEGREES F             95.0
   HIGH TEMPERATURE JOINT WIDTH, INCHES  .18970
   LOW TEMPERATURE, DEGREES F              73.0
   LOW TEMPERATURE JOINT WIDTH, INCHES   .20800
   MIN. TEMPERATURE OBSERVED, DEGREES F    -20.

VERTICAL
   JOINT WIDTH, INCHES                     .190
   LOAD TRANSFER, PERCENT                  78.0
```

```
                 ***********
                 * OVERLAY *
                 ***********

OVERLAY TYPE                                    AC

   CREEP MODULUS, PSI                       350000.
   DYNAMIC MODULUS, PSI                    4000000.
   THICKNESS, INCHES                          12.00
   DENSITY, PCF                               140.0
   POISSONS RATIO                              .300
   THERMAL COEFFICIENT, PER DEGREE F       .0000120
   BONDING STRESS, PSI                        500.0

NOTE - SLOPE OF FRICTION CURVE FOR INTERFACE BENEATH EXISTING
       PAVEMENT WILL BE MULTIPLIED BY RATIO OF NEW OVERBURDEN
       WEIGHT TO EXISTING OVERBURDEN WEIGHT.

BOND BREAKER WIDTH, FEET                        4.0


           ***********************
           * OTHER DESIGN INPUTS *
           ***********************

DESIGN TEMPERATURE CHANGES, DEGREES F
   EXISTING PAVEMENT                           100.
   OVERLAY                                     120.

DESIGN LOAD
   WEIGHT, POUNDS                           24000.0
   WIDTH, INCHES                               24.0
```

```
**************************************************************************
    REFLECTION CRACKING PROGRAM OUTPUT
**************************************************************************


            ***************
            * BETA VALUES *
            ***************

BEFORE OVERLAY                            .8531
AFTER OVERLAY
  BONDED                                  .9353
  UNBONDED                                .9223


        ***************************
        * SLOPE OF FRICTION CURVE *
        ***************************

BEFORE OVERLAY                          .414E+05
AFTER OVERLAY                           .100E+06


         ***********************
         *   MAXIMUM STRESSES   *
         * IN EXISTING PAVEMENT *
         *        (PSI)         *
         ***********************

CONCRETE, BEFORE OVERLAY                  223.0


           ********************
           ********************
           ** OVERLAY STRAINS **
           **      IN/IN     **
           ********************
           ********************

SHEAR                                   .119E-04
TENSILE                                 .198E-02
```

APPENDIX K

DETERMINATION OF POISSON'S RATIO, MODULUS OF ELASTICITY, AND TENSILE STRAIN AT FAILURE FOR ASPHALTIC CONCRETE (Ref. 16)

In order to estimate the Poisson's ratio, modulus of elasticity, and tensile strains, it is necessary to measure the vertical and horizontal deformations of the specimens and to relate these deformations to the applied load. Thus, deformation measuring equipment as well as continuous load-deformation recording equipment is required.

K.1 Equipment

Loading equipment capable of applying a compressive load at a controlled deformation rate, preferably 2 inches (5.08cm) per minute, is required as a guided loading head with parallel platens such as the die set with attached loading strips shown in Figures K.1 and K.2, respectively. The gyratory press probably should not be used to apply the load since accurate load-vertical deformations and load-horizontal deformations must be continuously measured and recorded. These measurements on specimens of stabilized materials have been satisfactorily obtained at the Center for Highway Research at the University of Texas at Austin by using a linear variable differential transformer (Schaevitz Engineering Type 1000 DC-LVDT) to measure vertical deformation and a specially designed horizontal deflection device (Figure K.3) to measure horizontal deformations. The specifications for this device are contained in Section K.4. In addition, a load cell was used to measure the applied load. Figure K.4 illustrates this equipment in a testing mode.

Some means of continuously recording the loads and their corresponding vertical and horizontal deformations must be used since the rate of loading makes it impossible to manually record the observations. Project personnel at the Center for Highway Research have satisfactorily made such measurements by continuously recording the load-deformation relationships on two x-y plotters (Hewlett Packard Model 7001A).

If the Texas gyratory shear compactor is used, it is recommended that a pressure transducer be considered as a means of monitoring the load. This transducer can be inserted into the pressure system; however, the Center for Highway Research has not investigated this possibility. In addition, for materials exhibiting very small deformations per unit load it may be necessary to use equipment capable of measuring and recording deformations more precisely.

K.2 Test Procedure

(1) Determine the height and diameter of the test specimen.
(2) Calibrate horizontal deformation device (Section K.5).

(3) Center test specimen on loading head.

(4) Bring upper platen of die set into light contact with test specimen. Monitor load on the x-y plotter that is recording load versus vertical deformation.

(5) Place horizontal deformation device on rear platform with arms in light contact with specimen and lock arms into position.

(6) Load specimen at a deformation rate of 2 inches (5.1cm) per minute and record load versus vertical deformation and load versus horizontal deformation.

K.3 Calculation of Tensile Properties

The various tensile properties can be obtained by using the procedure outlined below and the equations shown in Table K.1. The analysis of an example problem is presented below.

K.3.1 Procedure

(1) From the load deformation curves obtained from the indirect tensile test (Figures K.6 and K.7) replot the corresponding vertical and horizontal deformations up to the failure load P_{Fail} (first break point) (Figure K.8).

(2) Determine the deformation ratio DR, the slope of the line of best fit, between the corresponding vertical and horizontal deformations up to the failure load (Table K.2).

(3) Determine the horizontal tangent modulus S_H, the slope of the line of best fit between load P_{Fail} and zero on the load-horizontal deformation curve (Figure K.7). The solution using the least squares method is shown in Table K.3.

(4) Solve the equations summarized in Table K.1 to determine the various tensile Properties.

K.3.2 Example

(1) Calculate tensile strength from Table K.1

$$S_T = 0.156 \frac{P_{max}}{h}$$

P = 325 pounds (Figure 11) (174.6kg),

h = 1.908 inches (4.848cm),

D = 4 inches (10.16cm),

S_T = 25.6 psi (176.5kN/m^2).

(2) Determine DR and calculate Poisson's ratio ν from Table K.2.

$$DR = \frac{\Sigma\, xy - \frac{\Sigma\, x\, \Sigma\, y}{n}}{\Sigma\, x^2 - \frac{(\Sigma x)^2}{n}} = 6.49$$

From Table K.1

$$\text{Poisson's ratio } \nu = \frac{0.0673DR - 0.8954}{-0.2494DR - 0.0156} = 0.281$$

(3) Determine $\frac{P}{X_T}$ and calculate modulus of elasticity E from Table K.3

$$S_H = \frac{\Sigma\, xy - \frac{\Sigma\, x \Sigma\, y}{n}}{\Sigma\, x^2 - \frac{(\Sigma x)^2}{n}} = 10.87 \times 10^4 \text{ lb./in.} (1.94 \times 10^4 \text{kg/cm})$$

From Table K.1

$$E = \frac{S_H}{h} \; 0.976\nu + 0.2692 = 3.017 \times 10^4 \text{ psi } (20.8 \times 10^4 \text{kN/m}^2)$$

(4) Calculate total tensile strain at failure ε_T from Figure K.7

X_{TF} = .0029 inches (.0074cm)

From Table K.1

$$\varepsilon_T = X_{TF} \; \frac{0.1185\nu + 0.03896}{0.2494\nu + 0.0673} = 1.53 \times 10^{-3}$$

K.4 Special Equipment Required to Determine Poisson's Ratio, Modulus of Elasticity, and Tensile Strain at Failure

The special equipment required to determine the various tensile parameters is as follows:

(1) A loading device capable of applying compressive loads at a controlled deformation rate of 2 inches(5.1cm)

(2) A guided loading head with parallel platens, such as a commercially available all-steel precision die set (Figure K.1);

(3) A pair of curved-face loading strips of the proper size, which are to be attached to the upper and lower platens of the die set (Figure K.2);

(4) A rear platform with a polished surface to be attached to the rear of the lower platen of the die set to support the horizontal deflection device (Figure K.9;

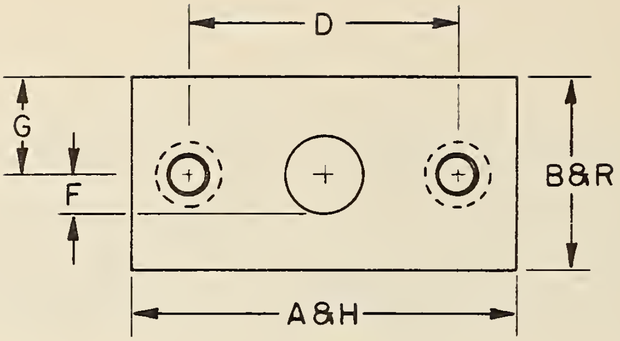
(5) A horizontal deformation measuring device (Figures K.10, K.11, K.12, K.13, and K.14);
(6) A calibrator for the horizontal deformation device (Figure K.15), the dimensions for which are presented in Figure K.15;
(7) An LVDT (linear variable differential transformer), such as Schaevitz Engineering Type 1000 DC-LVDT, to measure vertical deformation;
(8) A load cell to measure the applied load;
(9) Three DC power supplies, such as Hewlett-Packard Model 801C, to power the load cell, the horizontal deflection device, and the LVDT;
(10) two x-y plotters, such as Hewlett-Packard Model 7001A, to continuously record load and vertical and horizontal deformation;
(11) A load cell to die set connector (Figure K.16); and
(12) A digital voltmeter with which to set the various voltage requirements.

All of the above equipment except items 1, 6, 9, 10, and 12 is shown in Figure K.4, arranged in a testing mode.

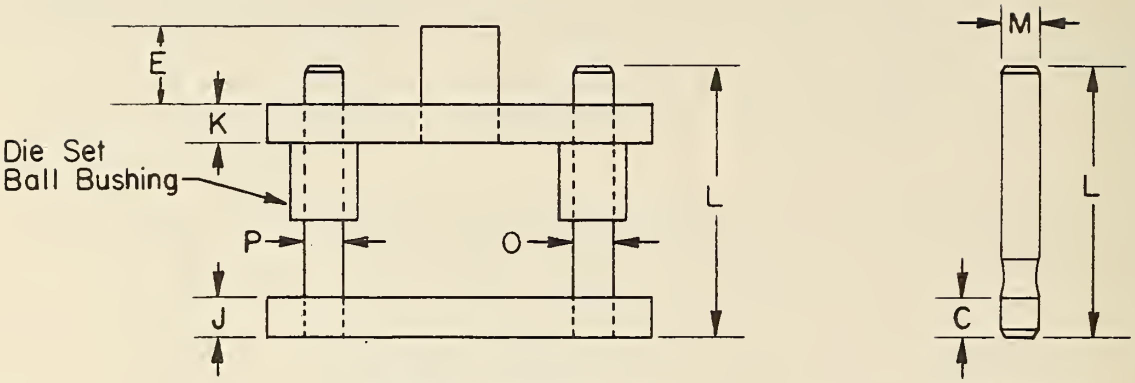
K.5 Horizontal Deformation Device Calibration

Calibrate the horizontal deformation device as follows:

(1) Plug in DC power supply and recording equipment and allow approximately 20 minutes for warmup.
(2) Adjust DC power supply output to approximately 6 volts. A digital voltmeter is preferred for this adjustment.
(3) Place horizontal deformation device in calibrating position (Figure K.17). Arm contacts should be centered on actuating screws and dial gage points. Caution should be exercised to assure that the arm contact points are lightly in contact with the actuating screw holder blocks.
(4) Lock arms in the above position.
(5) Connect the device to the power supply and to the recording equipment.
(6) Null the strain gage output and zero the dial gages.
(7) Select the desired MV/inch (1 in=2.54cm) range on the recorder.
(8) Using one of the arm activating screws of the calibrator, move the arm a given amount. Check for proper movement on the recording equipment. The amount of movement may be changed by altering the applied voltage to the strain gage or by altering the range selection of the recording equipment.
(9) Calibrate the other arm in a like manner.
(10) Continue the process several times to check for repeatability.



Die Set - Top View



Die Set - Front View

Guide Post

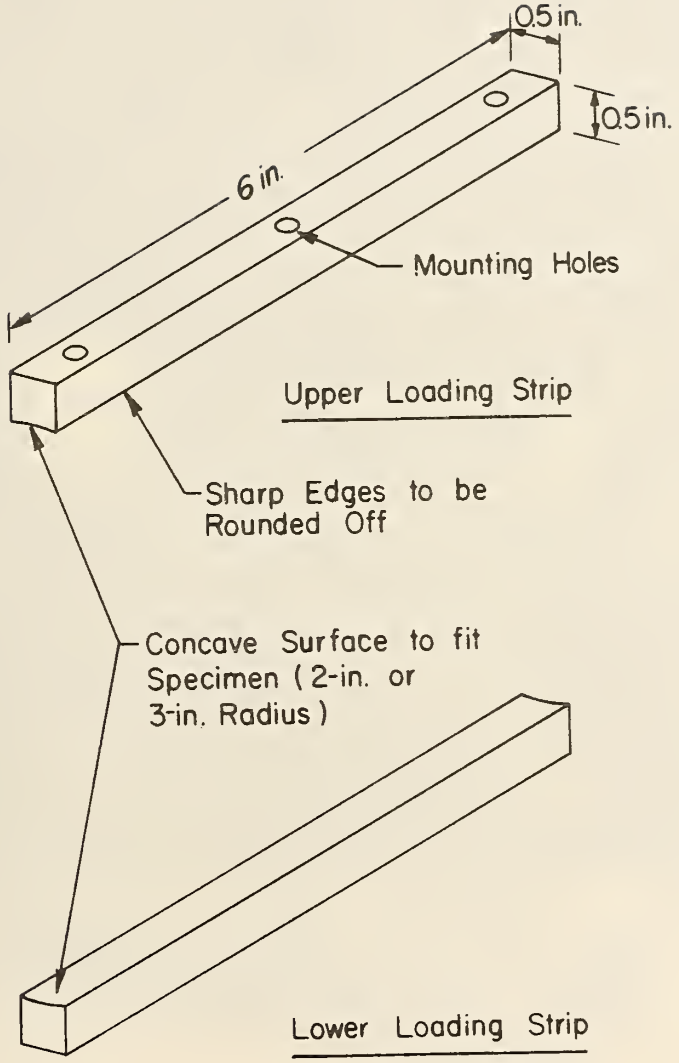
Die Space		Thickness		General Dimensions, in.			Guide Post (1)					Shank Dimensions, in.			Die Set Ball Bushing (2)	
Left to Right, in.	Front to Back, in.	Die Hldr, in.	Punch Hldr, in.				Diameter, in.		Length of Press Fit, in.	Length in.	Press Fit, in.				Working Bore	
A	B	J	K	D	H	R	O	P	C	L	M	E	F	G	Nom	Tol.
15¾	6	1⅜	1⅜	12¼	15¾	6	1¼	1¼	1¾	10	.002	1⅞	1	3	1¼	1.2497 1.2500

(1) Guide Posts are Hardened, Ground, and Hard Chrome Plated to Listed Diameter within Tolerance of +.0003 in. to -.0000 in.

(2) Thomson Interchangeable Die Set Ball Bushings Number DS-20

1 in=2.54cm

Figure K.1. Die set specifications.


0.5 in.
0.5 in.
6 in.
Mounting Holes
Upper Loading Strip
Sharp Edges to be Rounded Off
Concave Surface to fit Specimen (2-in. or 3-in. Radius)
Lower Loading Strip

1 in=2.54cm

Figure K.2. Upper and lower loading strip specifications.

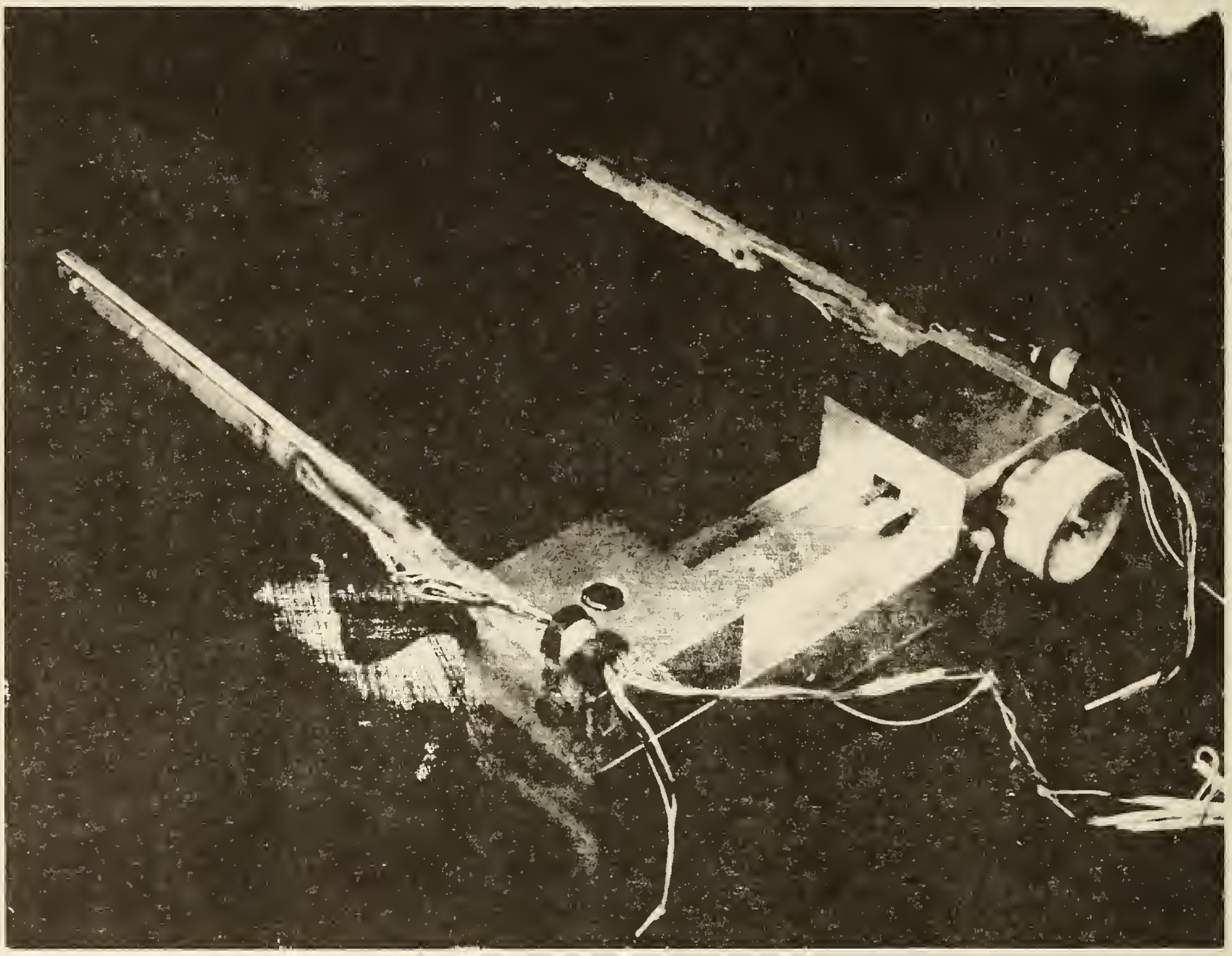


Figure K.3. Horizontal deflection device.

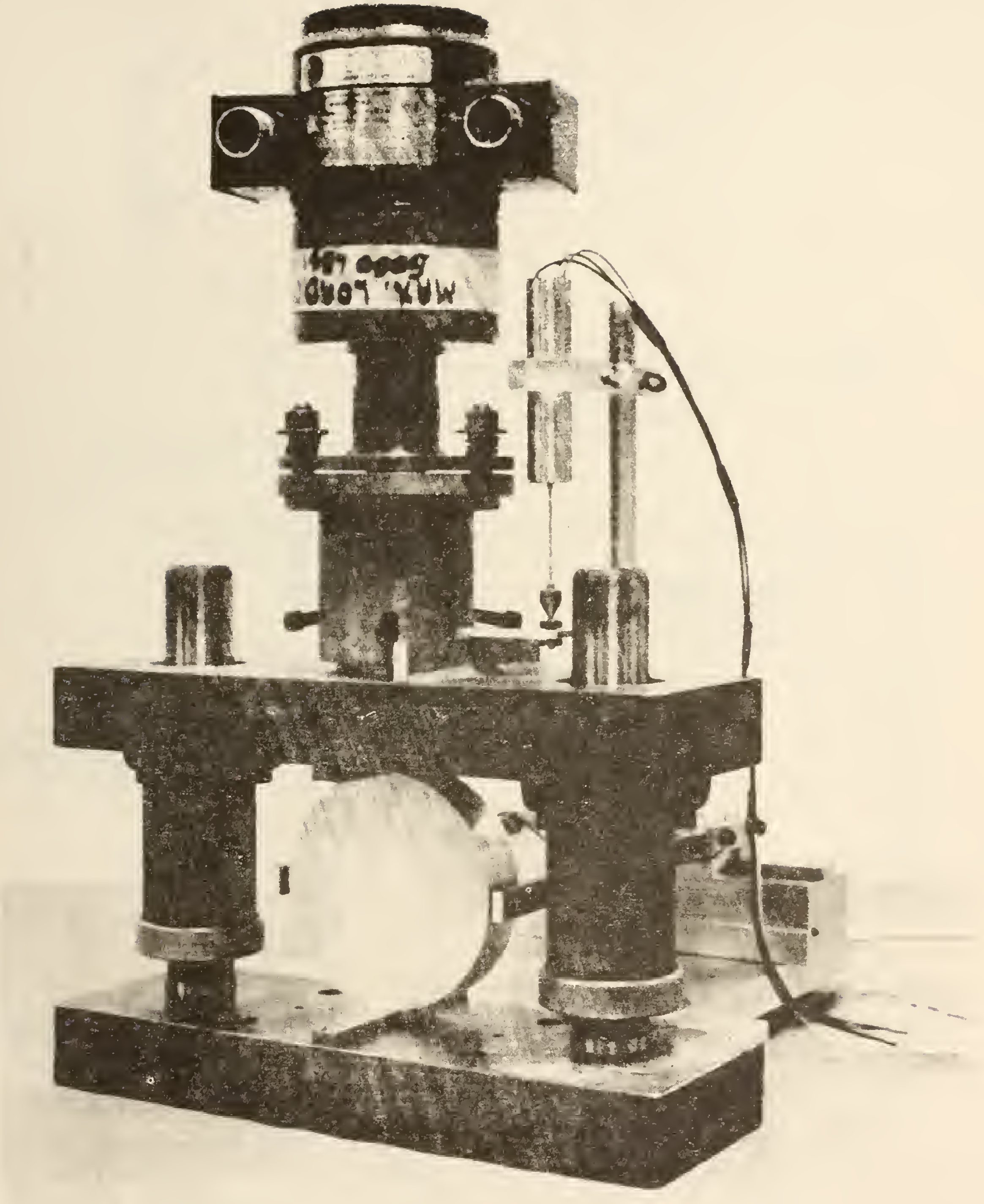
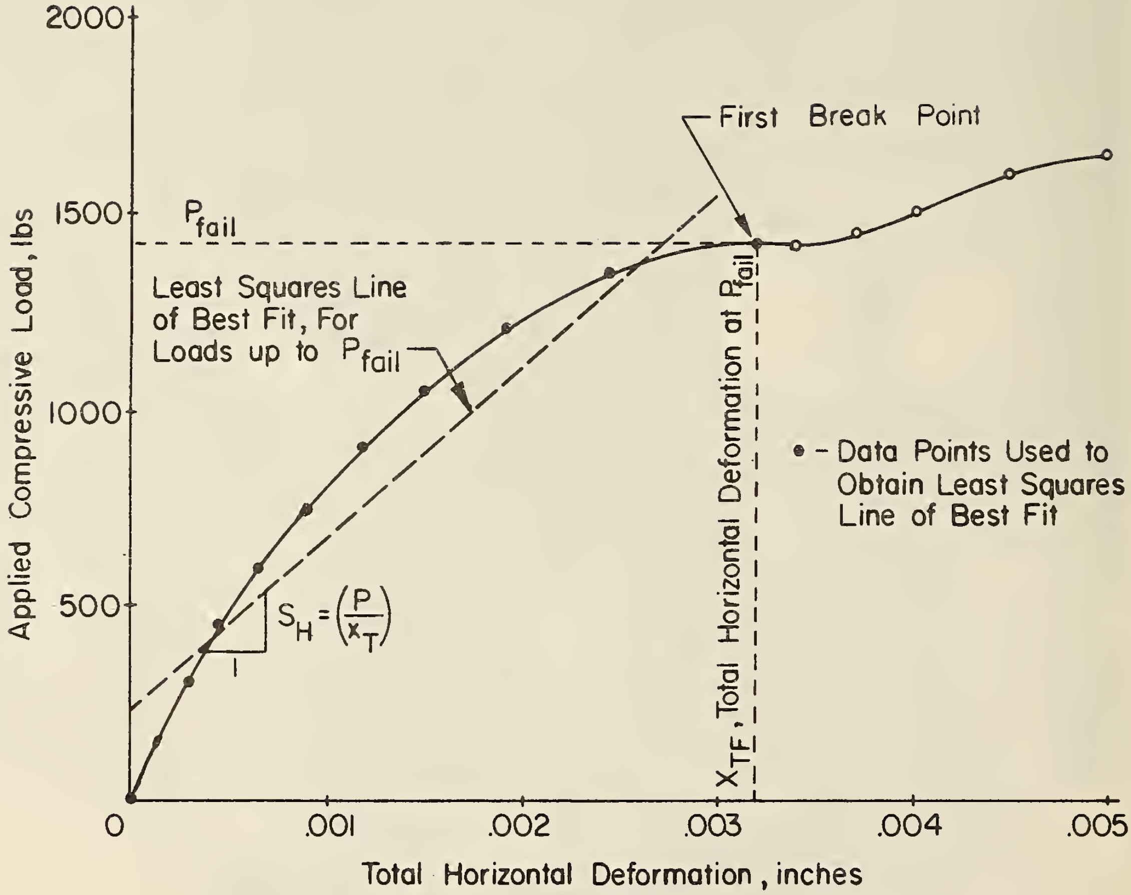


Figure K.4. Indirect tensile test equipment in test mode.



1 in=2.54cm
1 lb=.454kg

Figure K.5. Generalized characterization of load-horizontal deformation data.

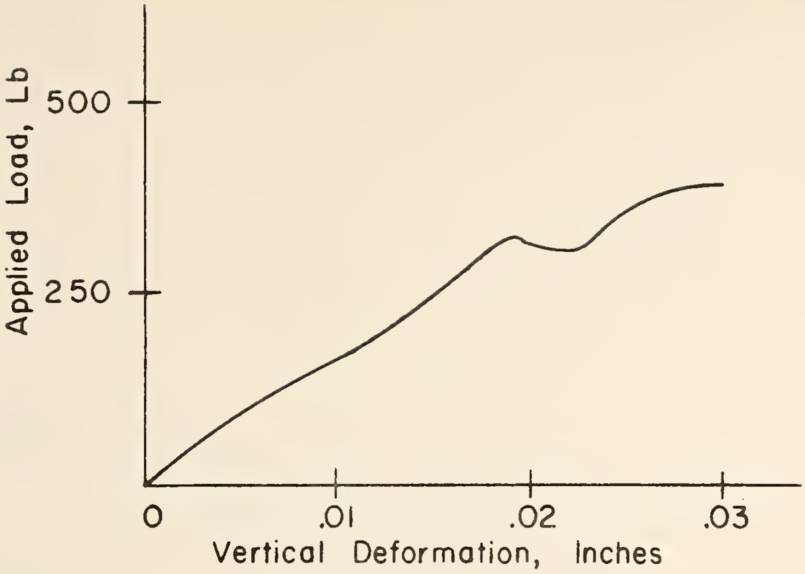
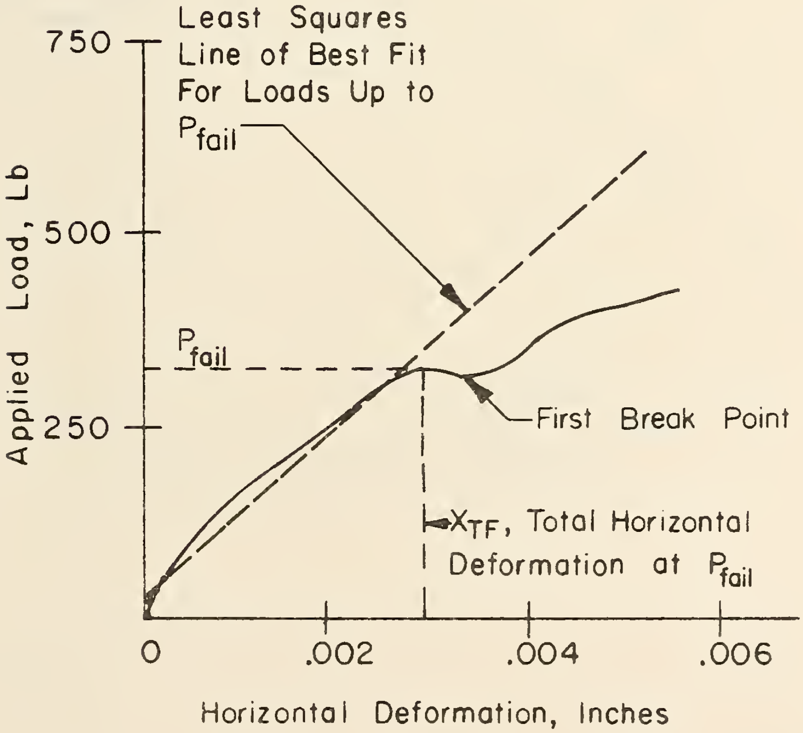


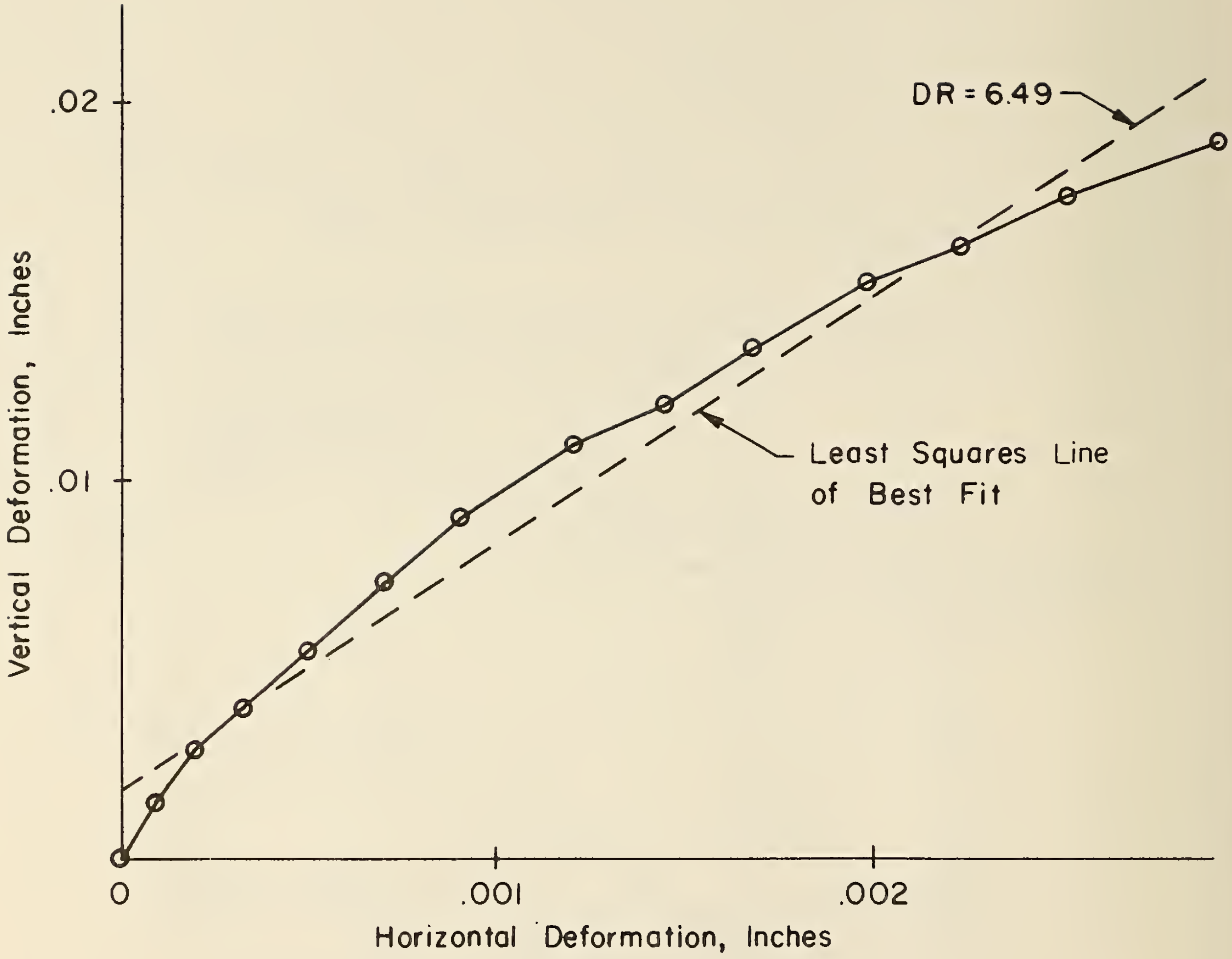
Figure K.6. Load vertical deformation curve.



1 in=2.54cm

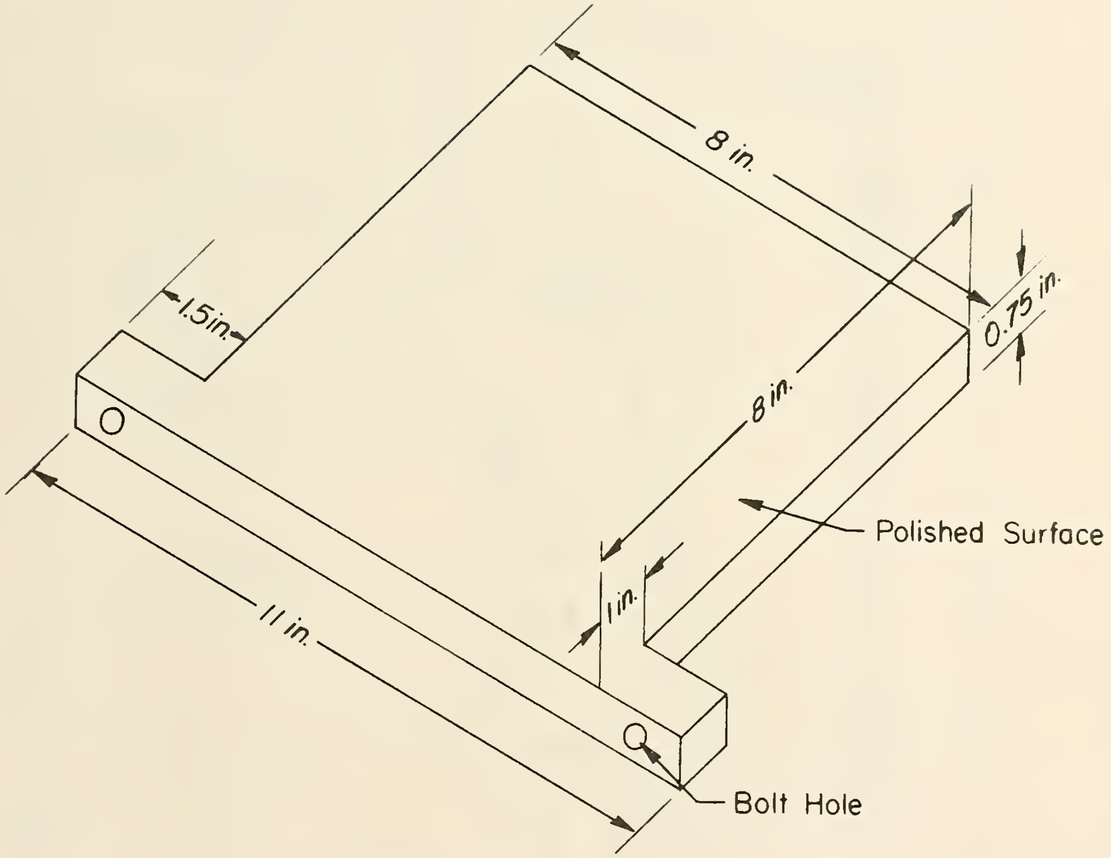
1 lb=.454kg

Figure K.7. Load-horizontal deformation curve.



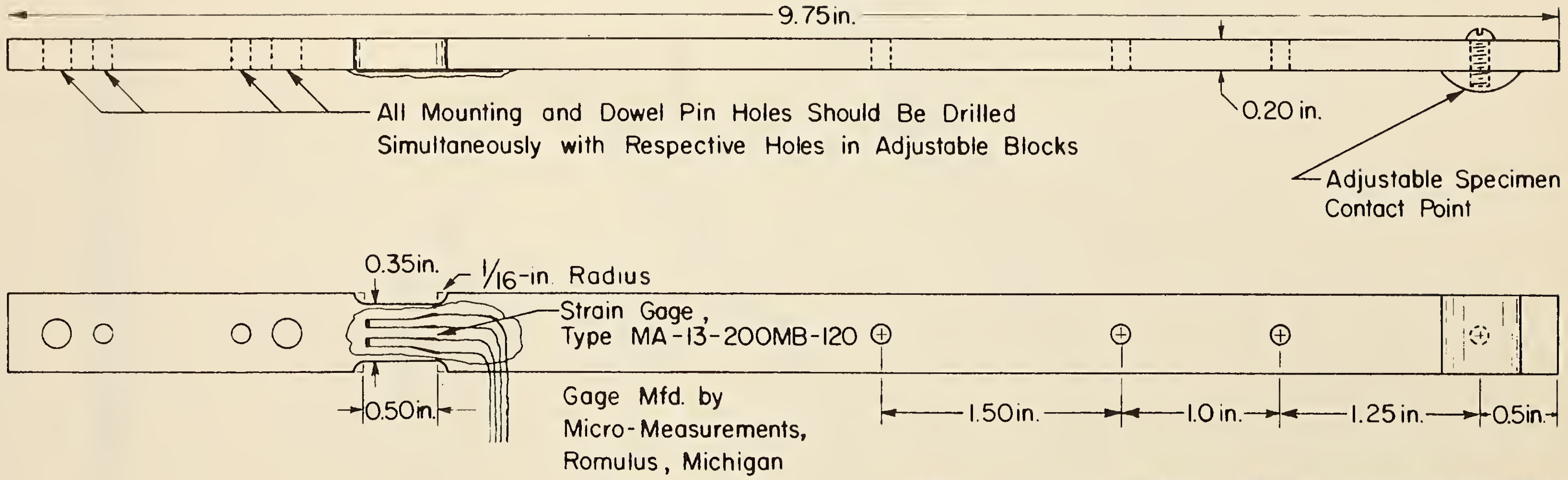
1 in=2.54cm

Figure K.8. Characterization of relationship between vertical and horizontal deformations.



1 in=2.54cm

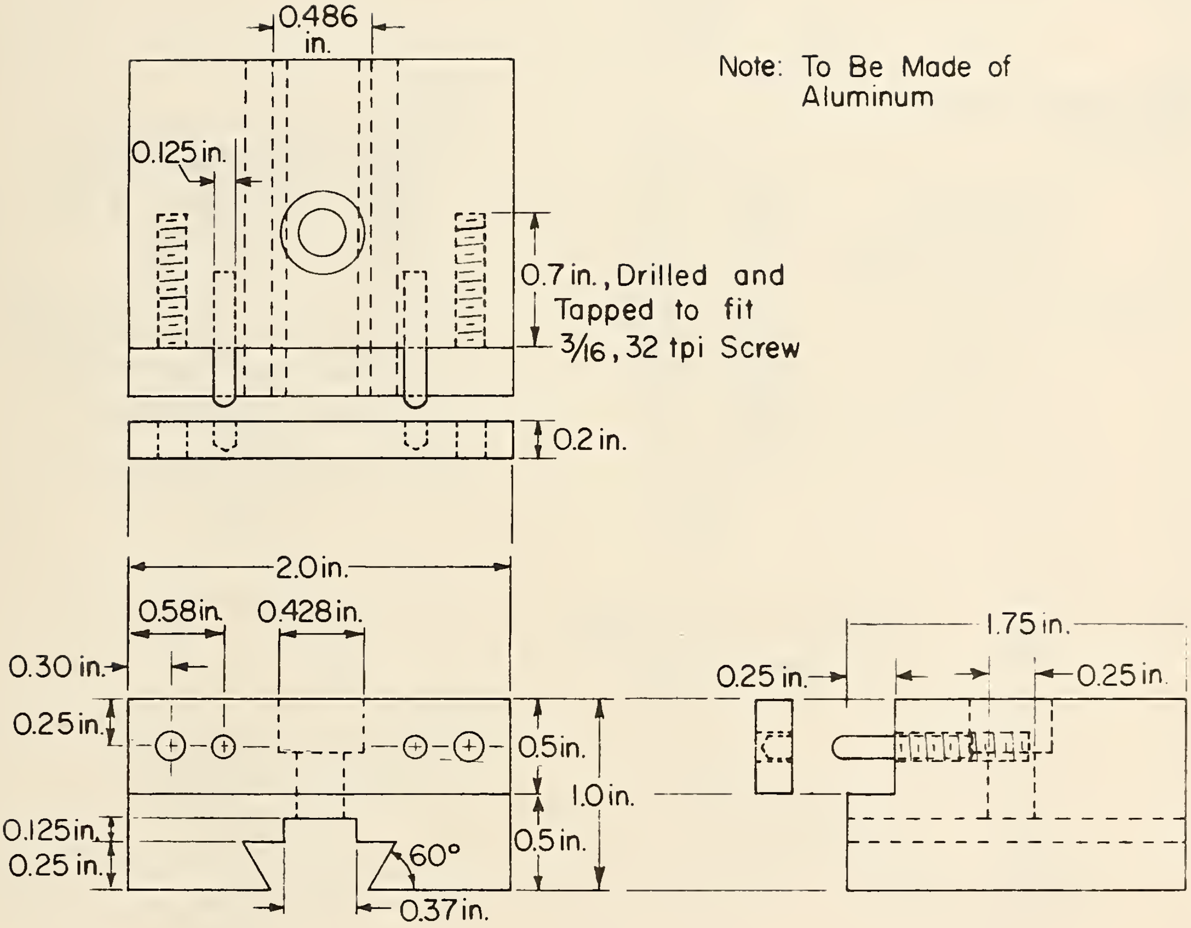
Figure K.9. Rear platform to support horizontal deformation device.


9.75 in.
All Mounting and Dowel Pin Holes Should Be Drilled Simultaneously with Respective Holes in Adjustable Blocks
0.20 in.
Adjustable Specimen Contact Point
0.35in.
1/16-in. Radius
Strain Gage, Type MA-13-200MB-120
0.50in.
Gage Mfd. by Micro-Measurements, Romulus, Michigan
1.50 in.
1.0 in.
1.25 in.
0.5in.

Note: Two Arms Required, Made of 2024-T4 Aluminum with 2 Sets of Gages per Arm

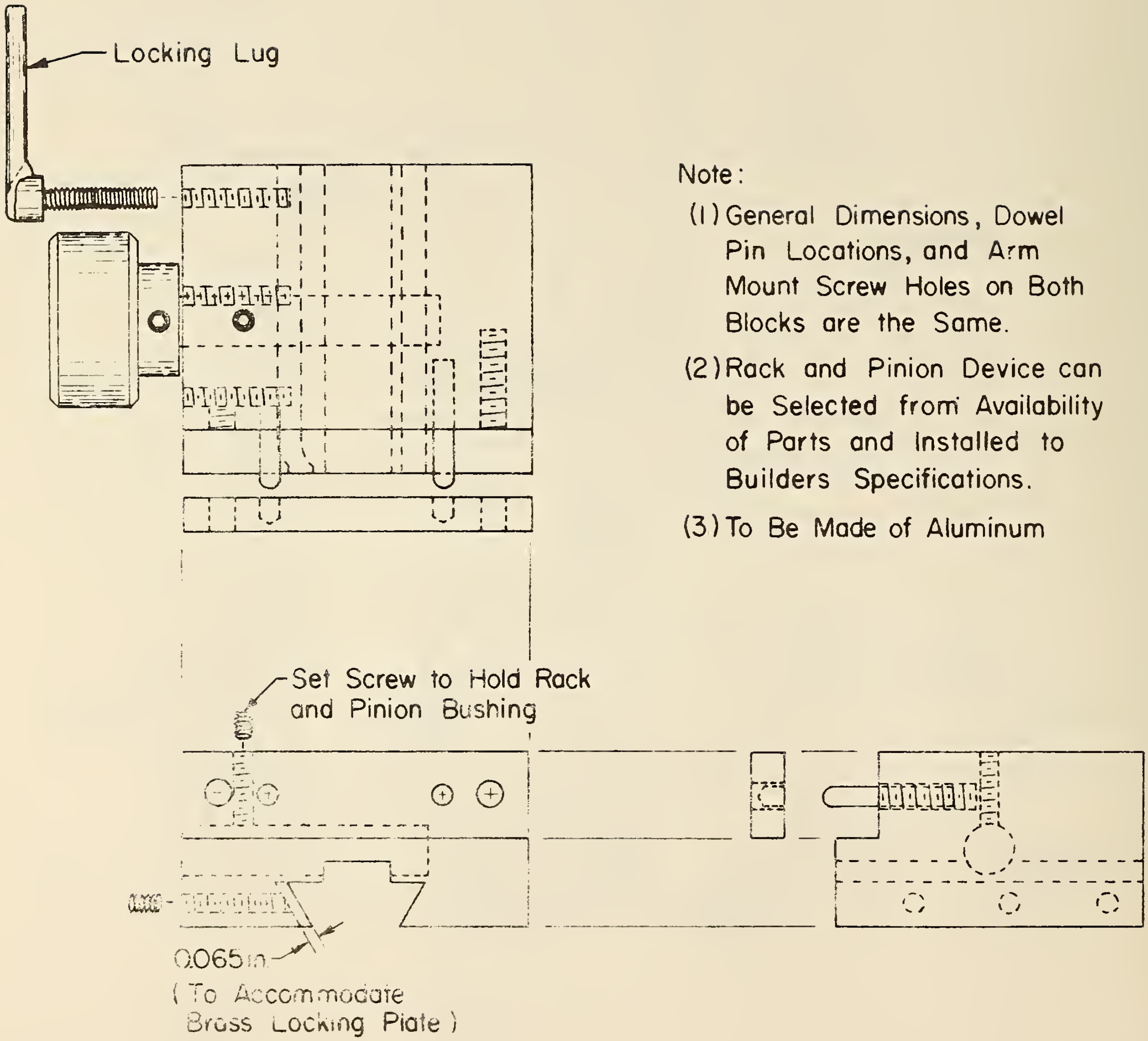
1 in=2.54cm

Figure K.10. Deformation arm for horizontal deformation device.



1 in=2.54cm

Figure K.11. Coarse adjustment block for horizontal deformation device.


Locking Lug
Set Screw to Hold Rack and Pinion Bushing
0.065 in.
(To Accommodate Brass Locking Plate)

Note:

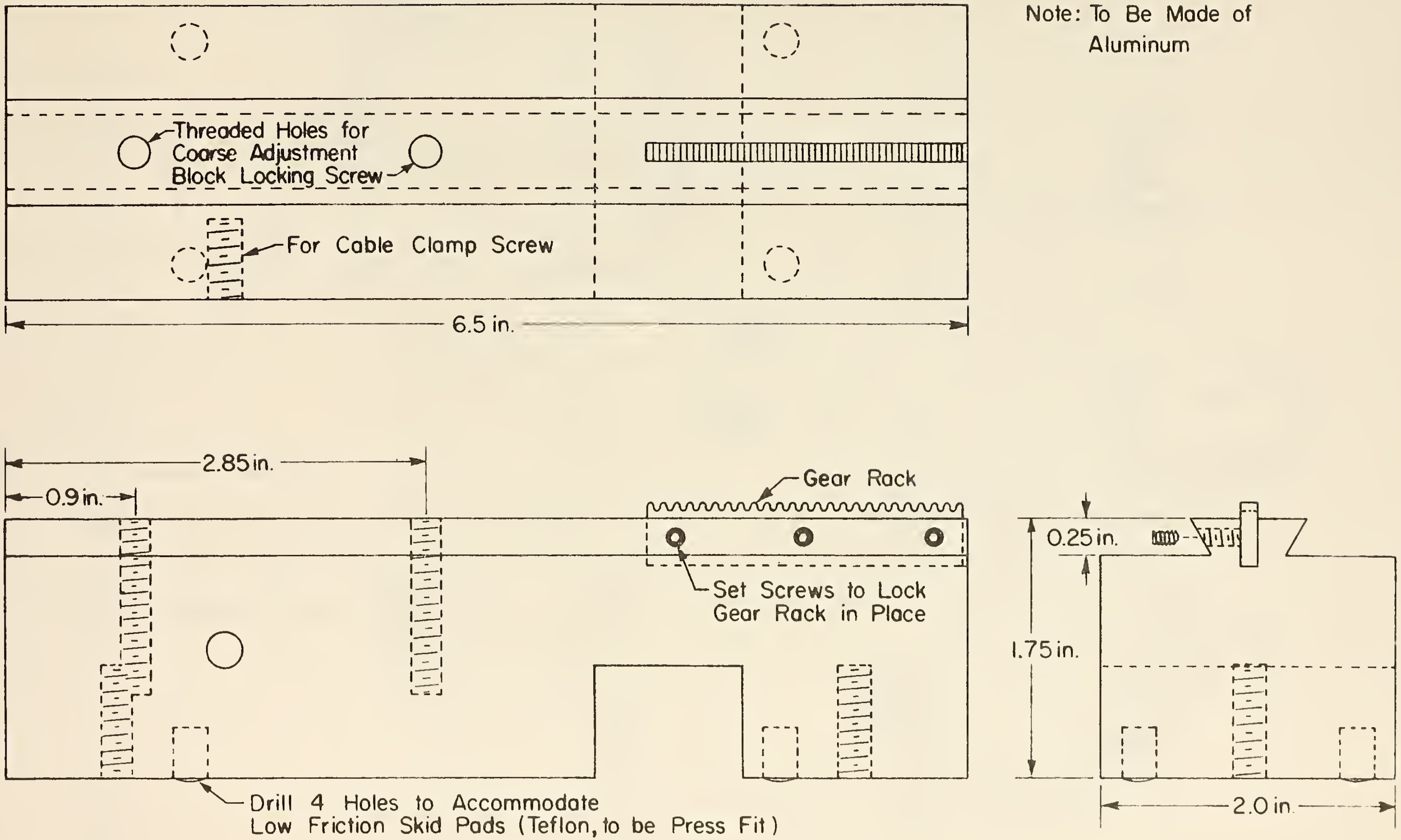
(1) General Dimensions, Dowel Pin Locations, and Arm Mount Screw Holes on Both Blocks are the Same.

(2) Rack and Pinion Device can be Selected from Availability of Parts and Installed to Builders Specifications.

(3) To Be Made of Aluminum

1 in=2.54cm

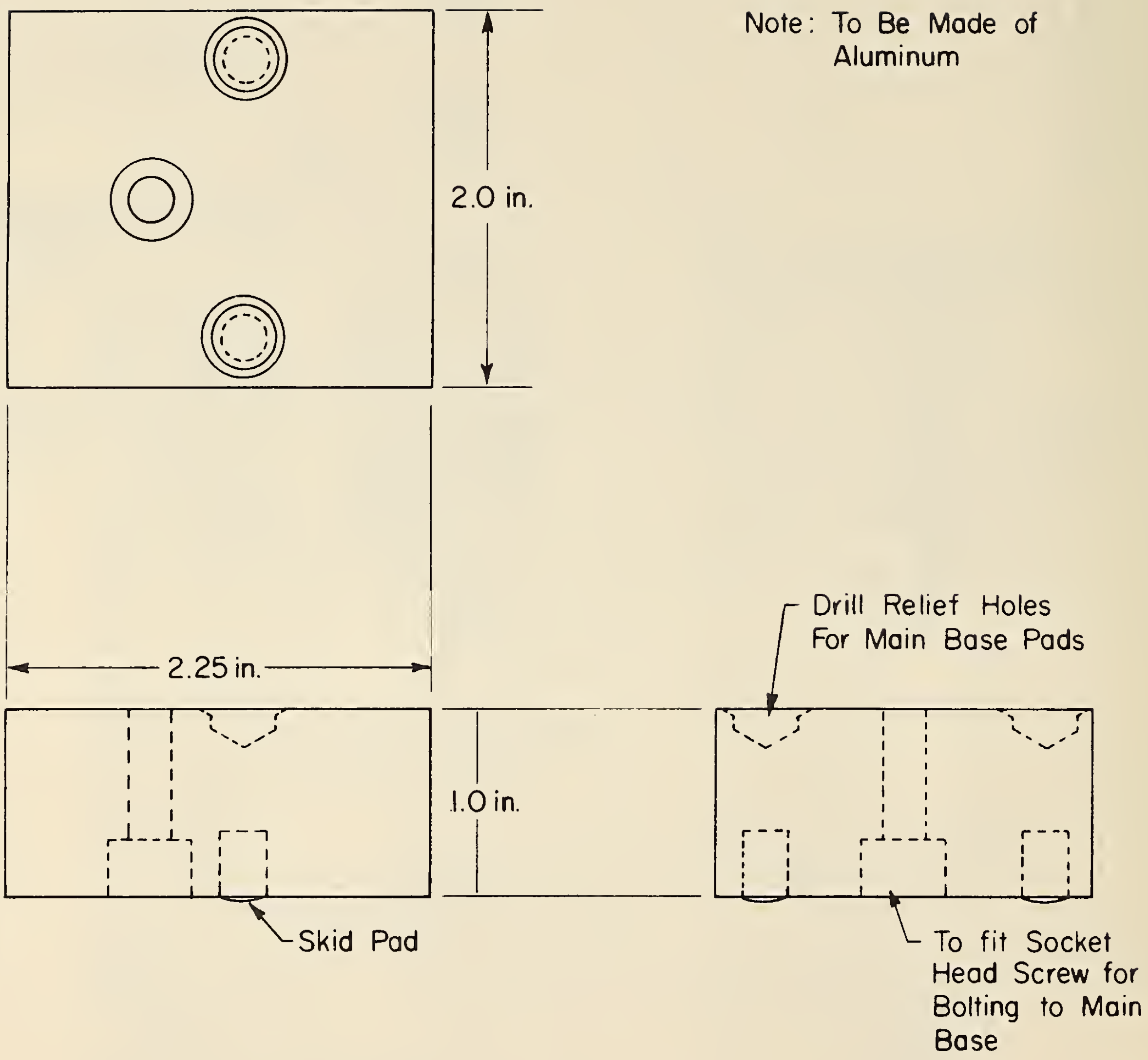
Figure K.12. Fine adjustment block for horizontal deformation device.


Threaded Holes for Coarse Adjustment Block Locking Screw
For Cable Clamp Screw
6.5 in.
2.85 in.
0.9 in.
Gear Rack
Set Screws to Lock Gear Rack in Place
Drill 4 Holes to Accommodate Low Friction Skid Pads (Teflon, to be Press Fit)
0.25 in.
1.75 in.
2.0 in.

Note: To Be Made of Aluminum

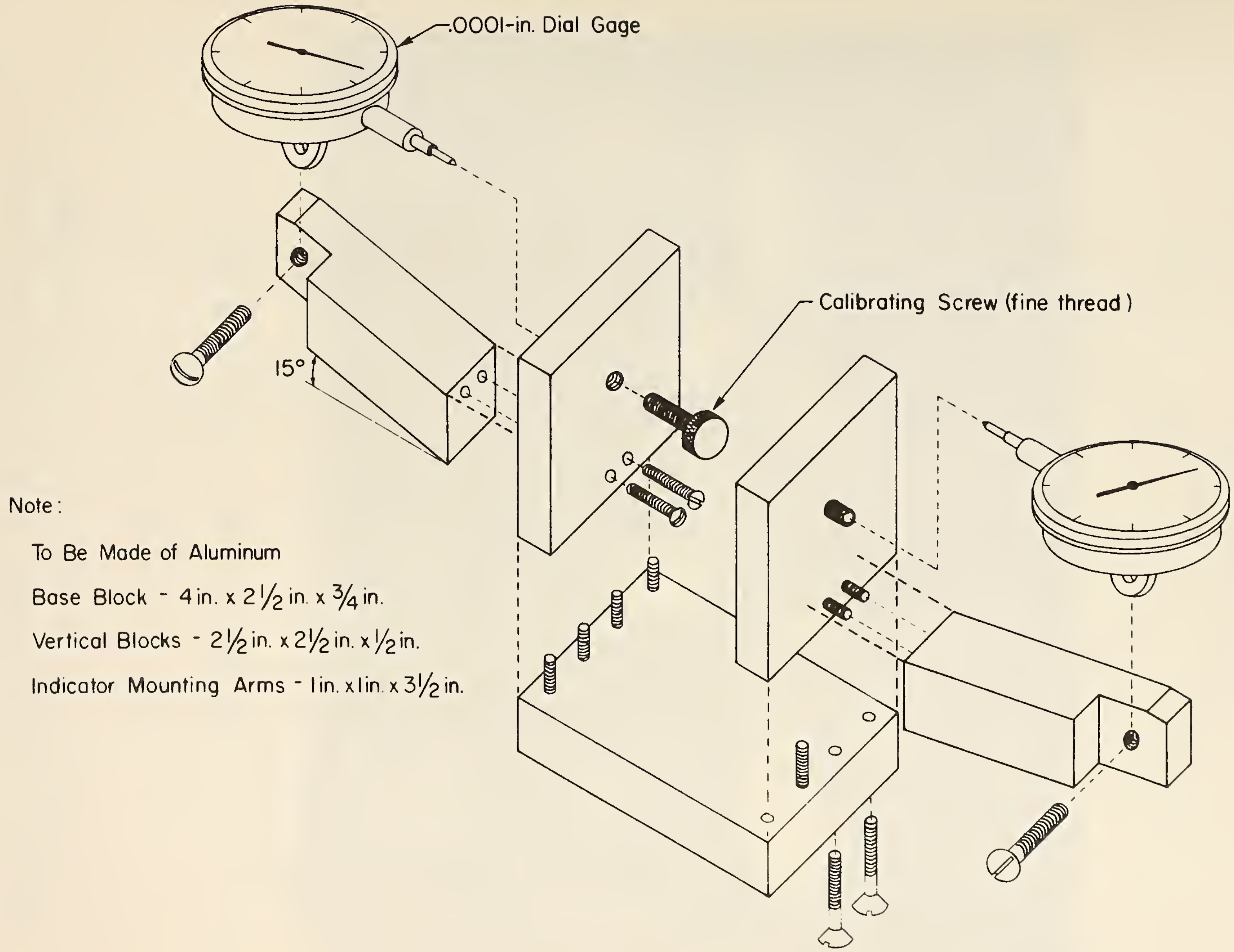
1 in=2.54cm

Figure K.13. Base for horizontal deformation device.


Note: To Be Made of Aluminum
2.0 in.
2.25 in.
1.0 in.
Skid Pad
Drill Relief Holes For Main Base Pads
To fit Socket Head Screw for Bolting to Main Base

1 in=2.54cm

Figure K.14. Base extension for horizontal deformation device.



Note:

To Be Made of Aluminum

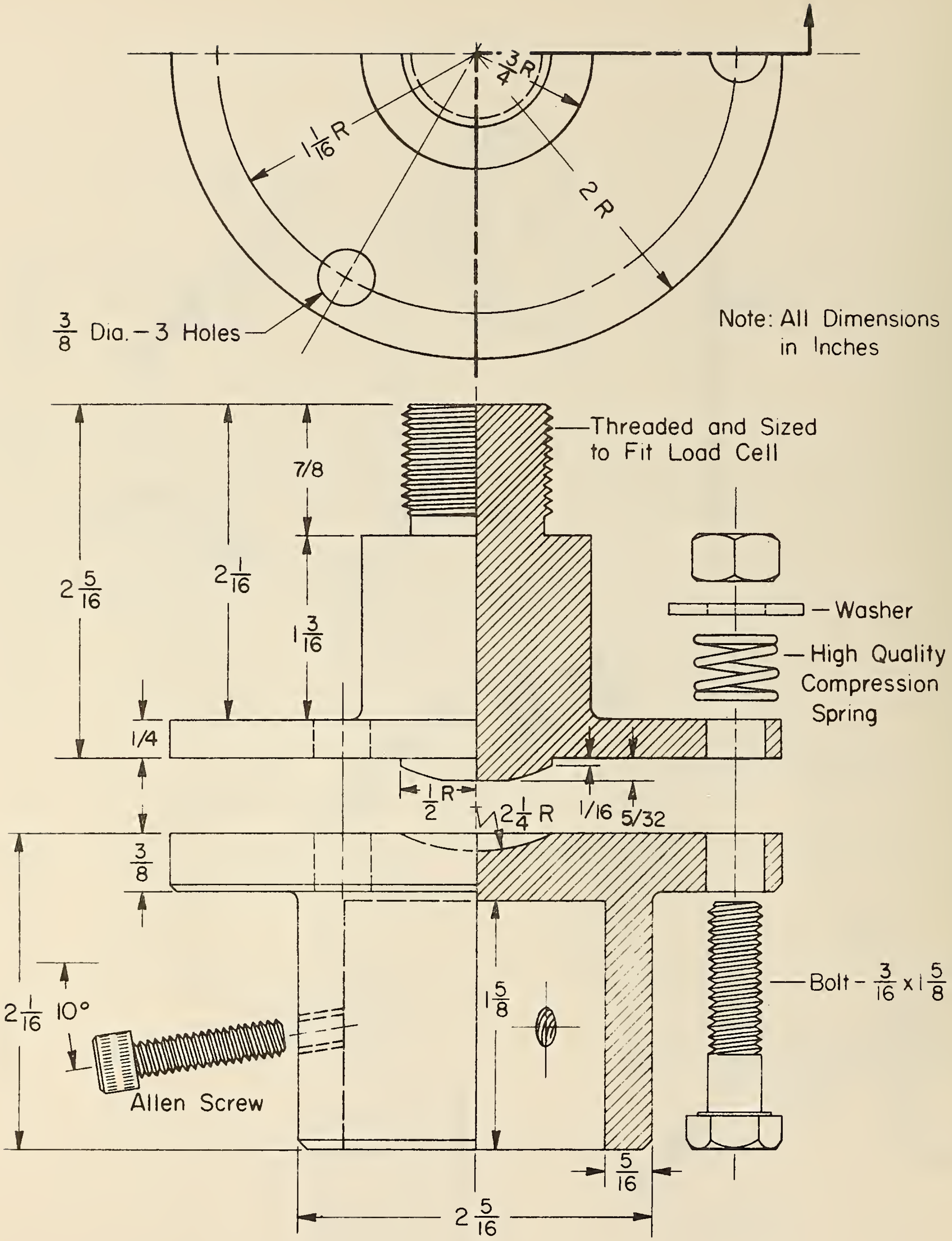
Base Block - 4 in. x 2 1/2 in. x 3/4 in.

Vertical Blocks - 2 1/2 in. x 2 1/2 in. x 1/2 in.

Indicator Mounting Arms - 1 in. x 1 in. x 3 1/2 in.

1 in=2.54cm

Figure K.15. Calibrator for horizontal deformation device.



1 in=2.54cm

Figure K.16. Connection between load cell and loadhead die set.

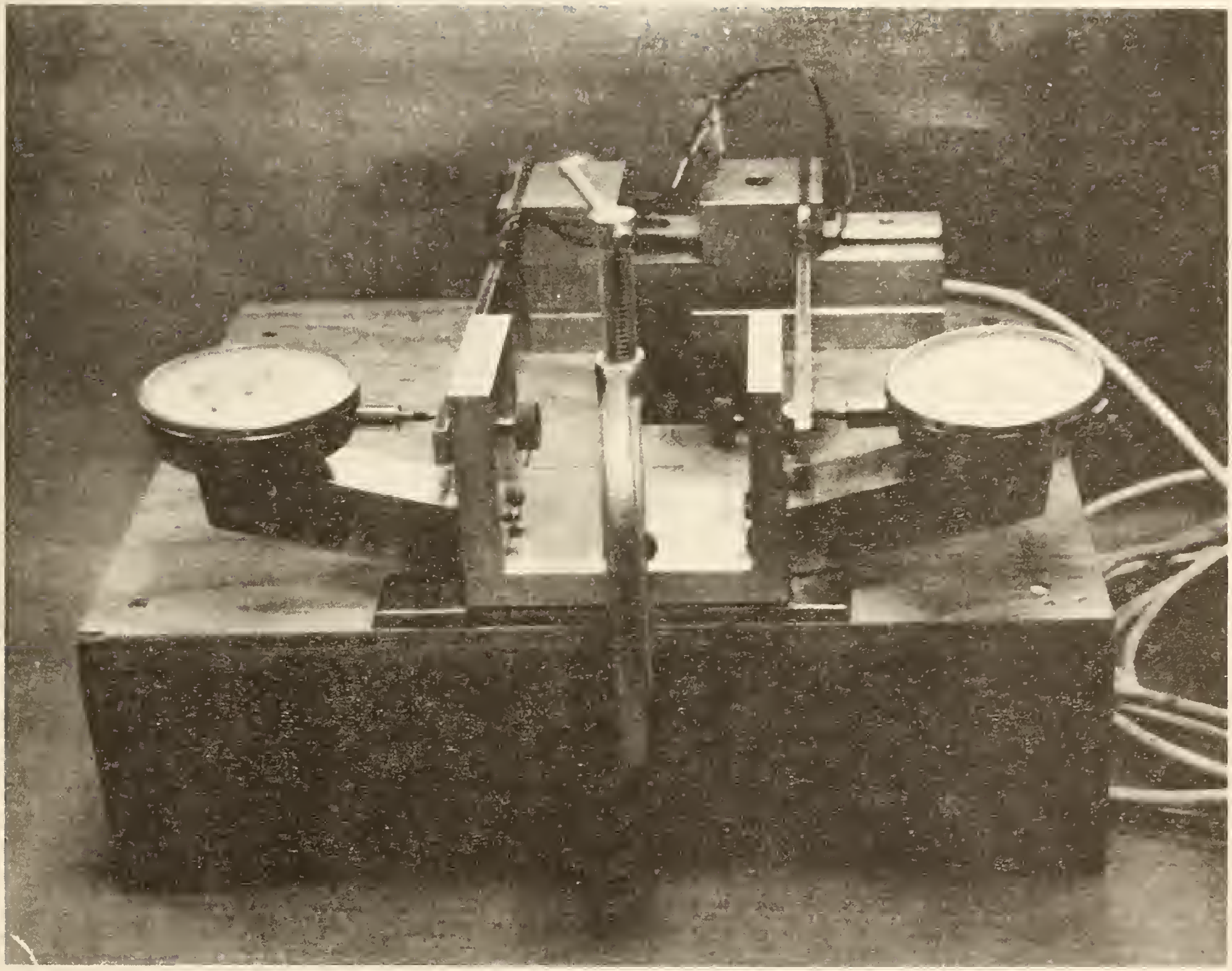


Figure K.17. Horizontal deflection device and calibrator.

TABLE K.1

EQUATIONS FOR CALCULATION OF TENSILE PROPERTIES

Tensile Property	Diameter of Specimen 4-Inch	 6-Inch
Tensile strength S_T, psi	$0.156 \frac{P_{Fail}}{h}$	$0.105 \frac{P_{Fail}}{h}$
Poisson's ratio ν	$\frac{0.0673DR - 0.8954}{-0.2494DR - 0.0156}$	$\frac{0.04524DR - 0.6804}{-0.16648DR - 0.00694}$
Modulus of elasticity E, psi	$\frac{S_H}{h}\ 0.9976\nu + 0.2692$	$\frac{S_H}{h}\ 0.9990\nu + 0.2712$
Total tensile strain at failure ε_T	$X_{TF}\ \frac{0.1185\nu + 0.03896}{0.2494\nu + 0.0673}$	$X_{TF}\ \frac{0.0529\nu + 0.0175}{0.1665\nu + 0.0452}$

P_{Fail} = total load at failure (maximum load P_{max} or load at first break point), in pounds (1 lb=.454kg);

h = height of specimen, in inches (1 in=2.54cm);

X_{TF} = total horizontal deformation at failure (deformation at the maximum load or at first break points), in inches (Figure K.5);

DR = deformation ratio $\frac{Y_T}{X_T}$ (the slope of line of best fit* between vertical deformation Y_T and the corresponding horizontal deformation X_T up to failure load P_{Fail});

S_H = horizontal tangent modulus $\frac{P}{X_T}$ (the slope of the line of best between load P and total horizontal deformation X_T for loads up to failure load P_{Fail}).

1 in=2.54cm
1 psi=6.9kN/m^2

---

* It is recommended that the line of best fit be determined by the method of least squares.

TABLE K.2

EXAMPLE CALCULATION OF DEFORMATION RATIO USING THE METHOD OF LEAST SQUARES

Load, in Pounds	X, Horizontal Deformation, in Inches $(x\ 10^{-4})$	Y, Horizontal Deformation, in Inches $(x\ 10^{-3})$	XY $(x\ 10^{-5})$	X^2 $(x\ 10^{-6})$
0	0	0	0	0
25	1.0	1.5	.015	.010
50	2.0	2.8	.056	.040
75	3.3	4.0	.132	.109
100	5.0	5.5	.275	.250
125	7.0	7.3	.511	.490
150	9.1	9.0	.819	.828
175	12.0	10.9	1.308	1.440
200	14.4	12.0	1.728	2.074
225	16.7	13.5	2.255	2.789
250	19.8	15.3	3.029	3.920
275	22.3	16.2	3.613	4.973
300	25.0	17.6	4.400	6.250
325	29.0	19.0	5.510	8.410
Σ	166.6	134.6	23.65	31.58
Average	11.90*	9.614*		

$$\text{Deformation Ratio} = \text{DR} = \frac{\Sigma\, xy - \dfrac{\Sigma\, x\ \Sigma y}{n}}{\Sigma\, x^2 - \dfrac{(\Sigma x)^2}{n}} = 6.49$$

---

* These values used to determine the position of the line of best fit.

1 in=2.54cm
1 lb=.454kg

TABLE K.3

EXAMPLE CALCULATION OF HORIZONTAL TANGENT MODULUS USING THE METHOD OF LEAST SQUARES

	X, Horizontal Deformation, in Inches (x 10^{-4})	Y, Load, in Pounds	XY (x 10^{-2})	X^2 (x 10^{-6})
	0	0	0	0
	1.0	25	.250	.010
	2.0	50	1.000	.040
	3.3	75	2.475	.109
	5.0	100	5.000	.250
	7.0	125	8.750	.490
	9.0	150	13.650	.828
	12.0	175	21.000	1.440
	14.4	200	28.800	2.074
	16.7	225	37.575	2.789
	19.8	250	49.500	3.920
	22.3	275	61.325	4.973
	25.0	300	75.000	6.250
	29.0	325	94.250	8.410
Σ	166.6	2275	398.575	31.583
Average*	11.900	162.5		

1 in=2.54cm
1 lb=.454kg

$$S_H = \frac{\Sigma\, xy - \frac{\Sigma\, x\ \Sigma\, y}{n}}{\Sigma\, x^2 - \frac{(\ \Sigma\, x\ )^2}{n}} = 10.87 \times 10^4 \text{ lb./in.} (1.94 \times 10^4 \text{kg/cm})$$

---

* These values are used to determine the position of the line of best fit.

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77-67

BORROW

FEDERALLY COORDINATED PROGRAM OF HIGHWAY RESEARCH AND DEVELOPMENT (FCP)

The Offices of Research and Development of the Federal Highway Administration are responsible for a broad program of research with resources including its own staff, contract programs, and a Federal-Aid program which is conducted by or through the State highway departments and which also finances the National Cooperative Highway Research Program managed by the Transportation Research Board. The Federally Coordinated Program of Highway Research and Development (FCP) is a carefully selected group of projects aimed at urgent, national problems, which concentrates these resources on these problems to obtain timely solutions. Virtually all of the available funds and staff resources are a part of the FCP, together with as much of the Federal-aid research funds of the States and the NCHRP resources as the States agree to devote to these projects.*

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems connected with the responsibilities of the Federal Highway Administration under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by keeping the demand-capacity relationship in better balance through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements which affect the quality of the human environment. The ultimate goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge of materials properties and technology to fully utilize available naturally occurring materials, to develop extender or substitute materials for materials in short supply, and to devise procedures for converting industrial and other wastes into useful highway products. These activities are all directed toward the common goals of lowering the cost of highway construction and extending the period of maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural designs, fabrication processes, and construction techniques, to provide safe, efficient highways at reasonable cost.

6. Prototype Development and Implementation of Research

This category is concerned with developing and transferring research and technology into practice, or, as it has been commonly identified, "technology transfer."

7. Improved Technology for Highway Maintenance

Maintenance R&D objectives include the development and application of new technology to improve management, to augment the utilization of resources, and to increase operational efficiency and safety in the maintenance of highway facilities.

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* The complete 7-volume official statement of the FCP is available from the National Technical Information Service (NTIS), Springfield, Virginia 22161 (Order No. PB 242057, price $45 postpaid). Single copies of the introductory volume are obtainable without charge from Program Analysis (HRD-2), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.

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